Oil Shale Resources of Nova Scotia

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ABSTRACT

Oil shale occurrences have been historically reported in the Cape Breton Island, northern mainland and southern mainland areas of Nova Scotia. Twelve of these occurrences were investigated for this study. Rocks from three of the areas gave oil yields of less than 25 litres per tonne (below oil shale grade) while the remainder gave oil yields greater than 25 litres per tonne (above oil shale grade). The rock types of oil shale grade include silicate-rich shale (Antigonish Basin, Cape St. Lawrence area), carbonaceous shale locally transitional to coal (Minas Basin), limy shale and petroliferous limestone associated with coal (Cumberland and Sydney Basins), silicate-rich shale and cannel shale associated with coal (Debert-Kemptown Basin, Mabou-Inverness coalfield), and silicate-rich shale, cannel shale and boghead shale associated with coal (Stellarton Basin and Trenton Syncline). Of the areas containing rocks with greater than 25 litres per tonne oil yield, the Stellarton Basin represents the Province's largest oil shale resource with an estimated 825 x 10^6 tonnes of oil shale and 168 x 10^6 barrels of shale oil *in situ*. The Antigonish Basin represents the second largest oil shale resource in the Province with an estimated 738 x 10^6 tonnes of oil shale and 75.6 x 10^6 barrels of shale oil *in situ*.

Only Stellarton oil shale deposits have oil yields comparable to such deposits elsewhere, such as those of New Brunswick and Australia, and they represent the most favourable resource for future interest as a source of oil. Development of indirect methods for utilization, identification of useful by-products of the shale oil recovery process, inexpensive mining and retorting methods and/or higher petroleum prices could enhance the economics of oil shale development at Stellarton. Potential multiple uses for oil shale include use as a concrete additive, as an asphalt additive, and for electric power generation. However, oil shale beds are of most immediate use as stratigraphic markers since they can be recognized and correlated across Stellarton Basin. The transition of some oil shale beds into coal suggests the use of oil shale as a coal exploration tool in Stellarton Basin.

Oil shale resources and organic-rich shale elsewhere in the Province may be important petroleum source rocks. The occurrence of these rocks within strata that are age equivalent to known accumulations and occurrences of petroleum elsewhere in Nova Scotia and in New Brunswick suggests that they may have acted as regional petroleum source rocks. This possibility may have significant implications for petroleum exploration.

ACKNOWLEDGMENTS

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INTRODUCTION

Oil shale is a general term applied to all fine grained sedimentary rocks that yield liquid hydrocarbons in excess of 25 litres per tonne of rock when heated to about 500°C (Yen and Chilinganian, 1976; Cook *et al.*, 1981; Tissot and Welte, 1984). Lithologically, these rocks may be shale, marl or carbonates (Tissot and Welte, 1984), or transitional to coal and carbonaceous shale (Cook *et al.*, 1981). Oil shale of the Green River Formation of western USA is described as microlaminated kerogen- and fish-bearing carbonate (Boyer, 1982) and that of the Albert Formation as kerogen-rich dolomitic laminite (St. Peter, 1982). Liquid hydrocarbons (oil) derived from these rocks are produced through the thermal alteration of inherent organic matter at temperatures of 500°C. The bulk of organic matter in oil shale is typically contributed by material of algal origin (exinite macerals) with only minor contributions from material of (terrestrial) plant origin (humics: vitrinite, inertinite macerals; Hutton *et al.*, 1980). The algal material may be present as poorly preserved detritus or as discrete laminae or masses.

Interest in oil shale development has traditionally reflected oil pricing trends. The world's largest oil shale resource (1 trillion (10^{12}) barrels; Thorne, 1952), contained within the Green River Formation of Eocene age situated in the Green River, Washakie, Sand Wash, Uinta and Piceance Creek Basins of Wyoming-Utah-Colorado, is undeveloped primarily due to the availability of cheaper conventional oil. At the time of writing (1989), development of the Wyoming-Utah-Colorado oil shale for use as a direct source of oil is considered to be economic at $25-35/barrel (Vawter, 1989). Currently, activity in the region is directed toward enhancement of the oil shale development economics through advances in underground mining and retorting technology, oil shale waste management and development of alternate uses and markets for oil shale products. Similarly, New Brunswick oil shale is considered to be uneconomic on the basis of oil yield but is attracting attention for the potential offered in reducing sulphur emissions during co-combustion with high sulphur coal for thermal power generation (Macauley *et al.*, 1985). In Australia and China, the cost of developing oil shale using open pit mining methods is competitive with or lower than the world oil price (Wright and Browning, 1989; Lin Qian and Qiu Wang, 1989), such that development of the resource is warranted. Development of the Stuart oil shale deposit in Australia (with a resource of 3×10^9 barrels) is in the initial stages with commercial production scheduled for the year 2000 (Wright and Browning, 1989).

Oil shale has been reported in Nova Scotia since the 1800s in areas of Cape Breton Island, the northern mainland and the southern mainland (Annapolis Valley). Twelve areas are reported to contain oil shale (Fig. 1). All occur within Upper Paleozoic strata that range in age from middle Devonian to late Pennsylvanian (Fig. 2).

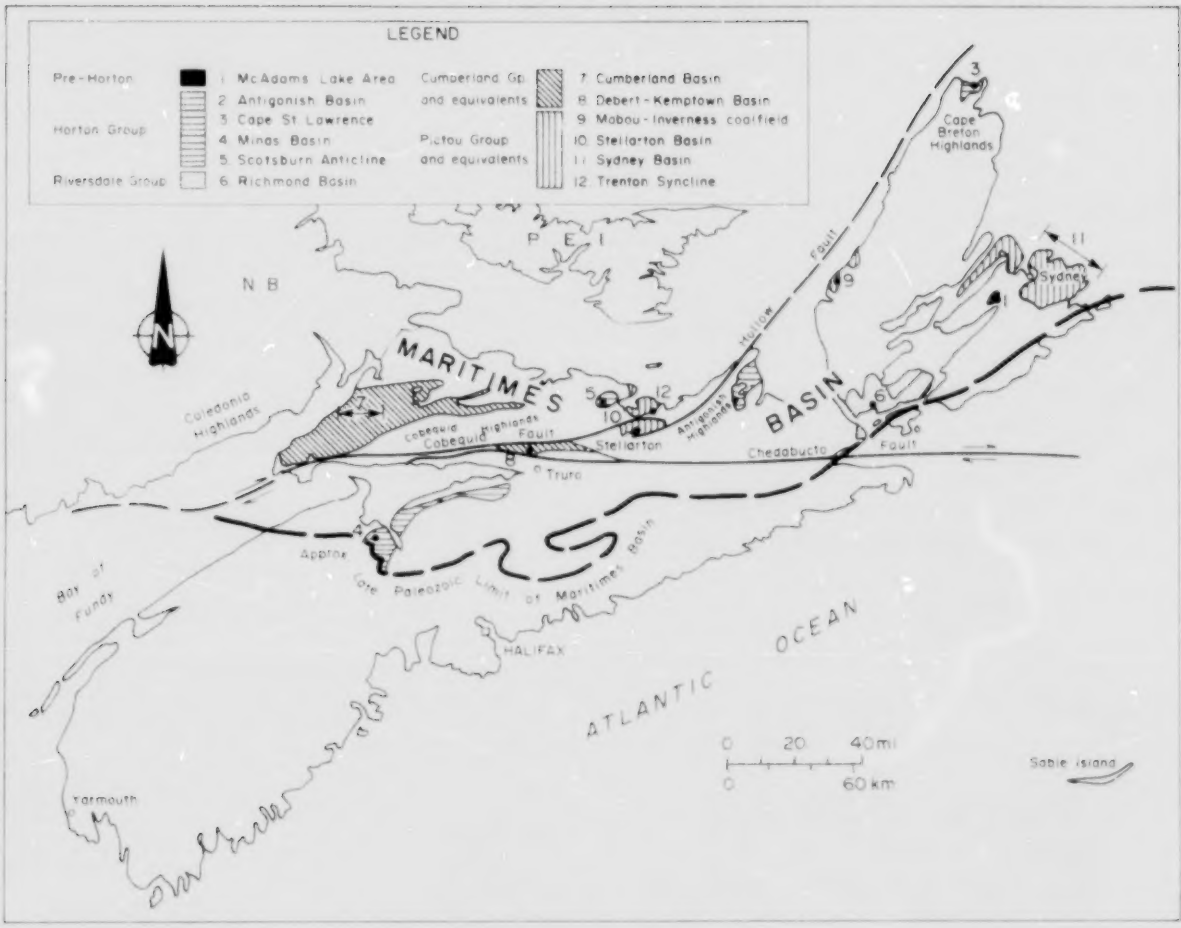

Figure 1. Areas of Nova Scotia reported to contain oil shale. Limit of Maritimes Basin after Naylor et al. (1989)

GENERAL GEOLOGY

All of the strata reported to be oil shale-bearing occur within an Upper Paleozoic sequence that was deposited within the regional Maritimes Basin (Figs. 1, 2). The basin developed as a depocentre due to strike-slip movement along major fault systems associated with the Devonian Acadian Orogeny. The Upper Paleozoic basin-fill was derived from adjacent upland areas (Caledonia, Cobequid, Antigonish and Cape Breton Highlands) and includes pre-Horton Group rocks and the Horton, Windsor, Canso, Riversdale, Cumberland and Pictou Groups. Except for the predominantly marine Windsor Group, the sequence is entirely of continental origin.

The localized pre-Horton (including the McAdam Lake Formation of southeast Cape Breton Island and the Knoydart Formation of Cape

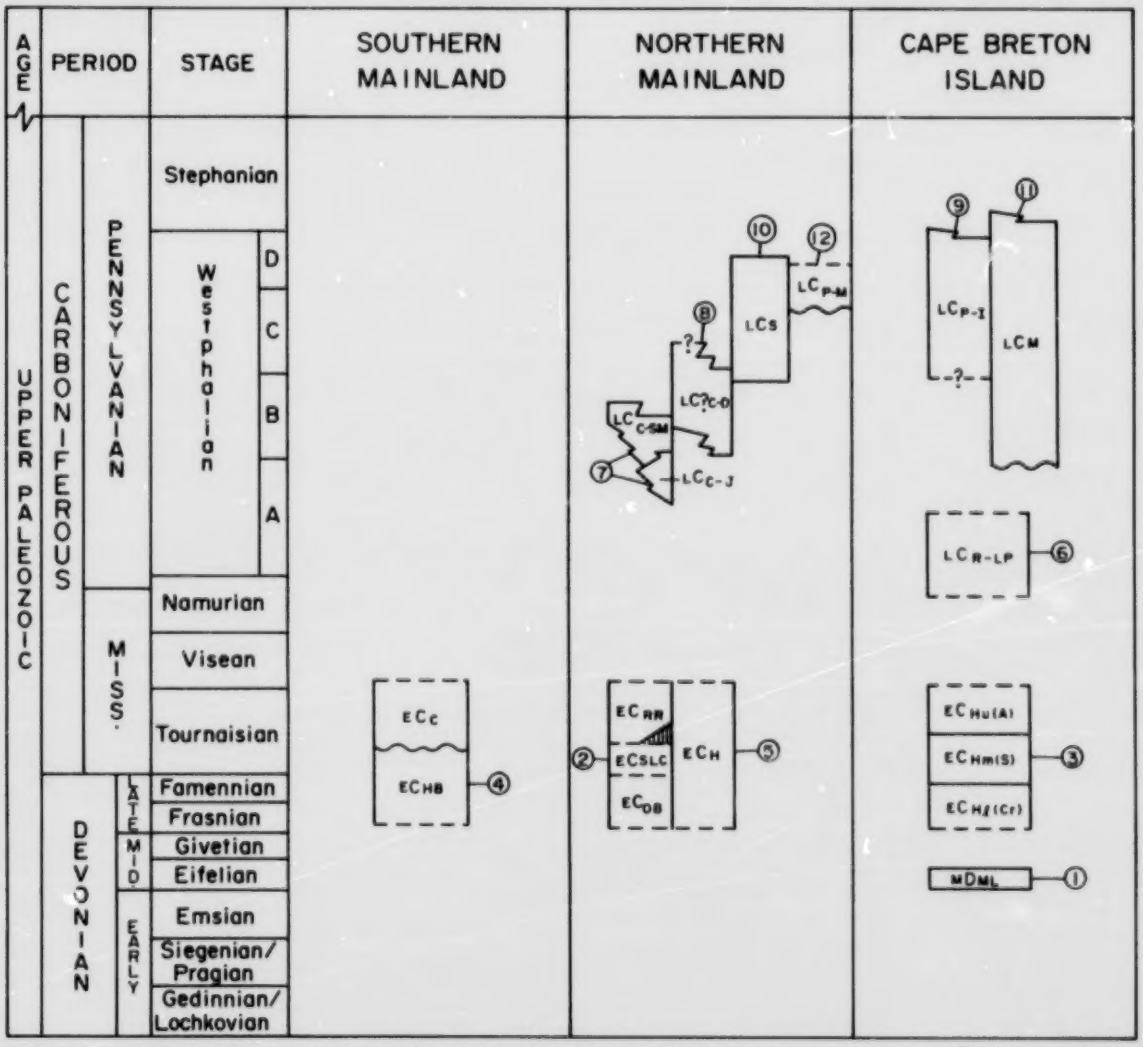

Figure 2. Age relationships of reported oil shale-bearing strata in the areas of Nova Scotia shown in Figure 1. MDML = McAdam Lake Formation, ECOB = Ogden Brook Formation, ECSLC = South Lake Creek Formation, ECRR = Rights River Formation,, ECHl(Cr) = Lower Horton (Craignish) formation, ECHm(S) = Middle Horton (Strathlorne) formation, ECHu(A) = Upper Horton (Ainslie) formation, ECHB = Horton Bluff Formation, ECc = Cheverie Formation, ECH = Horton Group (undivided), LCR-LP = Lennox Passage formation, LCC-SM = Springhill Mines Formation, LCC-J = Joggins Formation, LC?C-D = Delaney Formation, LCP-I = Inverness Formation, LCS = Stellarton Formation, LCM = Morien Group, LCP-M = Merigomish Formation.

George) and regionally extensive Horton Group rocks represent the earliest period of sedimentation (mid to late Devonian) following the Acadian Orogeny (Murray, 1960; Boehner *et al.*, 1986). The strata comprise about 3000 m of complexly intertonguing alluvial fan, lacustrine and minor coal swamp deposits (Murray, 1960; Boehner *et al.*, 1986; Martel and Gibling, 1987, 1988; Hamblin, 1989).

Deposition of Horton Group strata was terminated by the expansion of the Atlantic Ocean into much of the Maritimes Basin during Viséan time. The incursion resulted in deposition of the Windsor Group, which comprises regionally extensive marine carbonate and evaporite units, up to 1000 m thick in central basin areas, and local alluvial fan and redbed sequences along margins (Howie and Barss, 1975; Boehner *et al.* 1986).

Subsequent retreat of the Windsor Sea effected deposition of 2000 m of fine grained, red and grey, fluvial-lacustrine deposits of the Canso Group (Late Viséan-Early Namurian). In central basin areas, the transition from marine (Windsor) to continental (Canso) deposition was gradational, whereas at sites near active sediment source areas fanglomerate facies dominated (Howie and Barss, 1975; Boehner *et al.*, 1986). The record of sedimentation within the basin following deposition of the Canso sequence is markedly different as it was a period of major coal formation associated with fluvial and local lacustrine deposition. The post-Canso sequence includes the Riversdale, Cumberland and Pictou Groups.

The Riversdale Group (Late Namurian - Westphalian A) is, in part, diachronous with the underlying Canso strata (Howie and Barss, 1975; Boehner *et al.*, 1986) and comprises a local basal conglomerate and grey fluvial sandstone and minor fine grained redbeds with thin coal seams (Gersib and McCabe, 1981). Coal of economic significance occurs at St. Rose and Port Hood (Hacquebard *et al.*, 1989; Calder and Naylor, 1989).

The Cumberland Group (Westphalian A-B) unconformably or disconformably overlies the Riversdale Group and comprises 3355 m (Howie and Barss, 1975) of alluvial fan, alluvial plain, lacustrine, coal-swamp and perhaps estuarine deposits (Calder, 1985a; Calder and Naylor, 1989). Coal belonging to the Cumberland Group is known to occur in the Joggins-Chignecto and Springhill coalfields. The coal-bearing strata of the Debert-Kemptown Basin are age equivalent (Howie and Barss, 1975; Donohoe and Wallace, 1982c, 1982d) and are provisionally included within the Cumberland Group (Calder and Naylor, 1989).

The Pictou Group (Westphalian B- ?Permian) is a regionally extensive unit, in part contemporaneous with the Cumberland Group, which comprises 1525 to <3600 m of red and grey non-marine fluvial and fluvial-lacustrine sediments (Howie and Barss, 1975; Gibling, 1985c; Boehner *et al.*, 1986). The coal-bearing Morien Group and Inverness and Stellarton Formations are stratigraphic equivalents to the Pictou Group and they represent the most widespread period of abundant coal formation and fluvial deposition within the Maritimes Basin (Hacquebard, 1986).

RESULTS

In order to determine the quality and quantity of potential resources in the 12 areas studied, investigation of the geology (thickness, continuity, distribution), composition (mineralogy, organic content), and oil yield of the rocks at each area was undertaken by the Nova Scotia Department of Mines and Energy (NSDME) beginning in 1985. Project work began in the Stellarton Basin (the best known and most studied oil shale occurrence of Nova Scotia) in 1985 and continued there in 1986. In 1987 and 1988 work focused on the lesser known occurrences of the Province.

Of the 12 areas investigated, the McAdams Lake, Scotsburn Anticline and Richmond Basin areas contain rocks that yield less than 25 litres of hydrocarbons per tonne (l/t) of rock - the lower limit for a rock to be considered an oil shale. The rocks reported as oil shale at these areas are best considered as possible petroleum source rocks or as organic-rich shale.

The other 9 areas have confirmed oil shale, defined as rocks showing hydrocarbon yields exceeding 25 litres per tonne. The largest oil shale resource of the Province occurs within the Stellarton Basin (825 x 10^6 tonnes; 168 x 10^6 barrels of shale oil *in situ*). Maximum oil yields (250 l/t) obtained from some Stellarton oil shale samples are comparable with those obtained from oil shale of New Brunswick (263 l/t; Smith and Gibling, 1987) and Australia (260 l/t; Hutton *et al.*, 1980), yet are far below values obtained for Wyoming-Utah-Colorado oil shale (460 l/t; Hutton *et al.*, 1980). The second largest resource in Nova Scotia occurs within the Antigonish Basin (738 x 10^6 tonnes; 75.6 x 10^6 bbls of shale oil *in situ*). Maximum oil yields are low for Antigonish oil shale at only 58.9 l/t.

The information presented in the following sections of this report is intended as a summary of the geology and composition of the 'oil shale' reported at each of the 12 areas, beginning with the oldest sites. Each summary incorporates the data of earlier workers with data generated by this project in order to provide a complete information base on each area. Following each summary section is a list of all relevant references as well as additional selected references on the local geology of that area (authors and year only). All of the references are given in full at the end of the report. Table 1 summarizes the principal workers in these areas and their major contributions to the understanding of the local oil shale geology.

Table 1. *Other workers' contributions to information on the 12 oil shale areas investigated.*

AREA	AUTHORS	MAJOR CONTRIBUTION
1. McAdams Lake - East Bay area	- Fletcher, 1878 - Gilpin, 1899; Chevron (Pounder 1979) - Potter, 1977 - McGregor, 1977; Pounder, 1979	- First described occurrences(s) - Sampling and testing of shales - Drilling - Age assignment, regional correlation
2. Antigonish Basin	- How, 1868 - Ells, 1909; Mazerolle and MacGillivray, 1974a, b; Potter, 1975, 1976a, b, 1977; Macauley and Ball, 1984; Rockwell and Munroe, 1984; Kaulkreuth and Macauley, 1986, 1987 - NSDME (Potter, 1976) - Benson, 1970, 1973; Boehner and Giles, 1982; Murray, 1960 - Mazerolle and MacGillivray, 1974a	- First described occurrence(s) - Sampling and testing of shales - Drilling - Age assignment, regional correlation - Other: detailed geological map of the oil shale bed
3. Cape St. Lawrence - Cape North area	- Brooks and Macfil, 1955 - Murray, 1960	- First described occurrence(s) - Age assignment, regional correlation
4. Minas Basin	- Fletcher, 1894 - Potter, 1977; Macauley and Ball, 1984; Avery, 1986 - Saarberg-Interplan (Quarch et al., 1979); - Bell, 1960; Murray, 1960	- First described occurrence(s) - Sampling and testing of shales - Drilling - Age assignment, regional correlation

5. Scotsburn Anticline	- Imperial Oil (Stewart et al., 1932) - Imperial Oil (Stewart et al., 1932); - Irving-Chevron, 1981 - Irving-Chevron, 1981; Donohoe and Wallace, 1932; Ryan et al., 1988	- First described occurrence(s) - Drilling - Age assignment, regional corrlation
6. Richmond Basin	- Fletcher, 1881 - Potter, 1977 - Shea and Wallace, 1962; Hacquebard, 1972	- First described occurrence(s) - Sampling and testing of shales - Age assignment, regional correlation
7. Cumberland Basin	- Ells, 1910; Olsson and Fournier, 1944 - Chevron, 1986; Kalkreuth and Gibling, 1987 - NSDME (Naylor et al.); - Bell, 1944; Hacquebard and Donaldson, 1964; Ryan and Boehner, 1988; Ryan et al., 1988	- First described occurrence(s) - Sampling and testing of shales - Drilling - Age assignment, regional correlation
8. Debert - Kemptown Basin	- Ells, 1909 - Potter, 1977 - NSDME 1975-1978 (Gillis et al., 1976; Smith and Gillis, 1978; Smith et al., 1977) - Lortie, 1979; Donohoe and Wallace, 1982	- First described occurrence(s) - Sampling and testing of shales - Drilling - Age assignment, regional correlation
9. Mabou-Inverness Coalfield	- Robbins, 1969 - Kalkreuth and Gibling, 1987 - NSDME (Potter, 1978) - Hacquebard and Donaldson, 1969; Hacquebard et al., in press	- First reference to area as possible occurrence(s) - Sampling and testing of shales - Drilling - Age assignment, regional correlation
10. Stellarton	- How, 1868 - Ells, 1909; Swinnerton, 1930, 1933; Douglas and Campbell, 1942; Kendler, 1950; Goudge, 1957a, b; Potter, 1974-77; Chevron, 1986; Macauley and Ball, 1984; Kalkreuth and Macauley, 1986, 1987; Paul, 1988 - Geological Survey of Canada 1873/4-1897; Acadia Coal Company, 1908-1954; Pioneer Coal, 1989; NSDME 1901-1987; Kendler and Bell, 1957-58; George Wimpey Engineering, 1977; Brinco/Suncor/Placer (Bielenstein et al., 1987), 1980-1987 - Bell, 1940; Hacquebard and Donaldson, 1969; Naylor et al., 1987; Yeo/Yeo and Ruixiang/Yeo et al. 1985-86 - Flynn, 1926 - Kendler, 1950; Haw, 1958	- First described occurrence(s) - Sampling and testing of shales - Drilling - Age assignment, regional correlation - Other: Investigation of retorting performance of shales :use of oil shale as raw material for cellular concrete
11. Sydney Basin	- Hartley (in Selwyn, 1871) - Kalkreuth and Gibling, 1987 - Nova Scotia Steel Corp./Dominion Coal Corporation/British Empire Steel Corp./Devco, 1874-present; NSDME, 1977-1988 - Bell, 1927, 1938, 1944; Hacquebard and Donaldson, 1970; Boehner and Giles, 1986	- First described occurrence(s) - Sampling and testing of shales - Drilling - Age assignment, regional correlation
12. Trenton Syncline	- Poole, 1863 - Swinnerton, 1930 - NSDME, (D'Orsay et al.) 1986 - Yeo, 1985, 1987; Yeo and Ruixiang, 1986, 1987; Dolby, 1986a, 1987; D'Orsay et al., 1986	- First described occurrence(s) - Sampling and testing of shales - Drilling - Age assignment, regional correlation

*Except for Bielenstien et al., 1988, references to drilling in Stellarton and Sydney are contained in various reports, including NSDME Annual Reports, and are too numerous to include here.

MIDDLE DEVONIAN (EIFELIAN)

The oldest reported occurrence of oil shale is of middle Devonian age. The occurrence is reported from the McAdams Lake area of Cape Breton Island.

McAdams Lake Area

Stratigraphy, Age and Depositional Environment

Fletcher (1878) first reported oil shale within strata of the McAdam Lake Formation of eastern Cape Breton Island (Table 1). The McAdam Lake Formation is about 340 m thick (Alcock, 1947) and comprises arkosic sandstone, conglomerate, shale and felsic tuff (Bell and Goranson, 1938a, 1938b) with minor oil shale (Fletcher, 1878, 1894; Neville, 1891; Gilpin, 1899, 1900; Ells, 1909; Bell and Goranson, 1938a, 1938b; Mazerolle and MacGillivray, 1974c) and minor, thin, uneconomic coal (Potter, 1977; Hacquebard, 1982). The formation overlies Lower Paleozoic (Cambrian to Early Ordovician) and Precambrian (Hadrynian) strata (Keppie, 1979) and is overlain disconformably to conformably by conglomerate of the Windsor Group (Bell, 1938; Kelley and MacKasey, 1965). It occupies an area of about 30 km^2 (Fig. 3).

Howie and Barss (1975) considered the formation to be part of the Horton Group of Devonian to Early Carboniferous age. However, plant fragments of *Arthrostigma - Psilophyton* (Bell and Goranson, 1938a, 1938b; Dorf and Cooper, 1943) and palynological analyses (McGregor, 1977; Pounder, 1979) indicate a late Lower to Middle Devonian age (near the Emsian - Eifelian boundary). The Murphy Brook Formation (Donohoe and Wallace, 1980), Colchester County, of late Emsian to early Eifelian age (Forbes *et al.*, 1979), is age equivalent to the McAdam Lake Formation.

The McAdam Lake Formation is considered to be non-marine (Bell and Goranson, 1938a, 1938b) and represents one of the earliest records of sedimentary accumulation following the Acadian Orogeny (Murray, 1960). The occurrence of thin coal seams in the strata also represents one of the earliest periods of coal formation in Eastern Canada (Hacquebard, 1982).

Table 2. Legend and Key to Symbols for Figs. 3-13 and 15-17.

LEGEND

- Triassic Rocks
- Permo-Carboniferous Rocks
- Pictou Group & equivalents (i.e. Stellarton Fm., Morien Gp.)
- Cumberland Group & equivalents (i.e. Delaney Fm.)
- Riversdale Group
- Canso Group
- Windsor Group
- Horton Group
- Devono-Carboniferous Rocks
- Carboniferous Granitoid Rocks
- Fountain Lake Group
- McAdam Lake Formation
- Pre-Devonian Rocks including Plutonic Rocks (e.g. H-D, Hs, Pr)

SYMBOLS

- Bedding orientation ... 60
- Geological Contact ...
- Unconformity (assumed) ...
- Fault ...
- Coal seam crop; observed, inferred ...
- Anticline, syncline ...
- Sample location; exact, general ... •, ○
- Sample number; surface, subsurface ... WSA-88-01, (DP-79-01)
- Drillhole location ... ⊙ P-59A
- Slope / shaft ...
- Pit ...
- Mine or quarry (abandoned or operating) ...

Oil Shale

The McAdam Lake Formation oil shale has been variously described as black, shiny-lustrous, bituminous shale (Fletcher, 1878, 1894; Gilpin, 1899), coal oil shale (Gilpin, 1899) and black and dark grey carbonaceous shale (Ells, 1909). Some portions of the shale were reported by Gilpin (1899) and Ells (1909) to burn freely and give oil yields of 15-20 gal./ton (75-100 l/t), comprising 40% heavy lubricating oil, 20% light oil, 20% kerosene and 20% pitch (Gilpin, 1899). The oil shale was reported to outcrop near the west shore of McAdams Lake, on a small brook near the lake and in a roadcut to the northeast of the lake (Fletcher, 1878; Ells, 1909; Mazerolle and

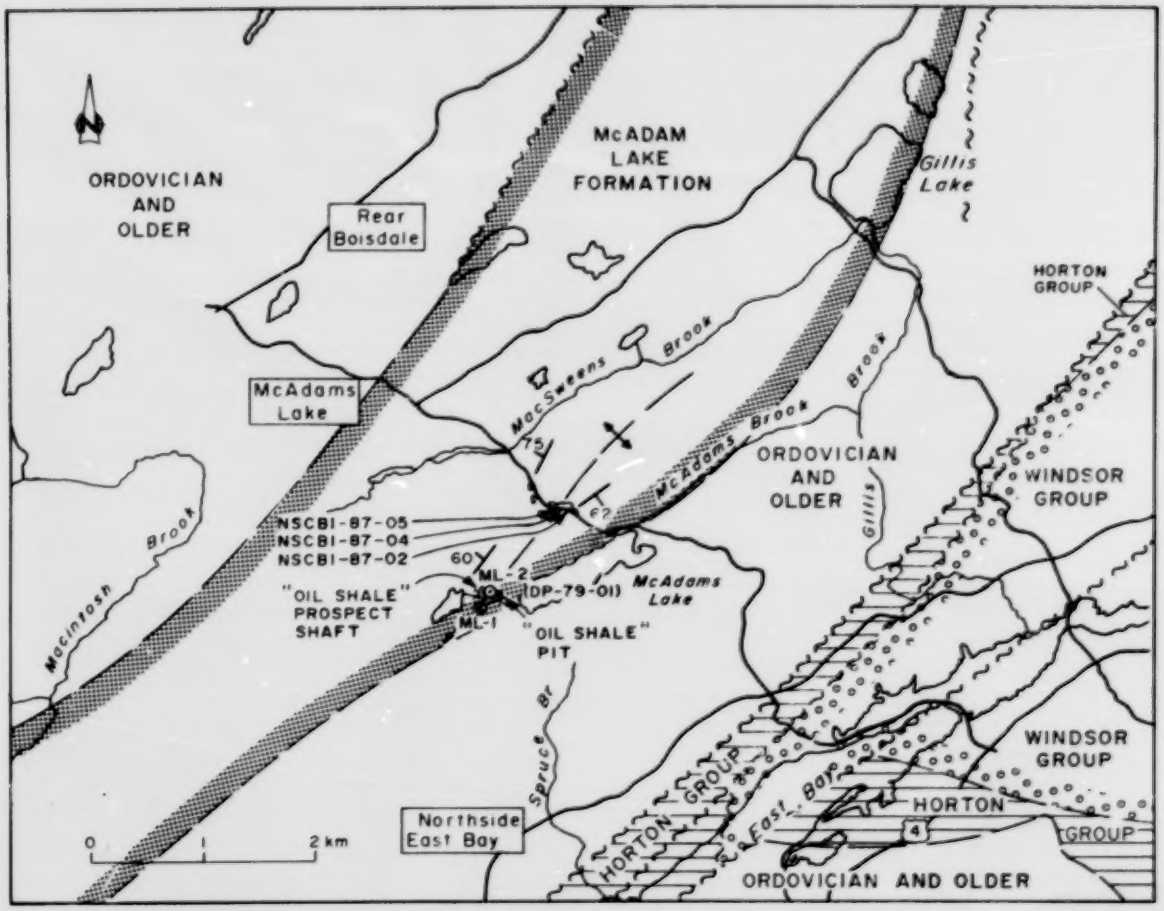

Figure 3. Geology of the McAdams Lake area (after Bell and Goranson, 1938b; Mazerolle and MacGillivray, 1974c; Boehner and Giles, 1986) showing the location of drillholes, and drill core and outcrop samples taken for testing. Bracketed sample numbers indicate drill core samples. See Appendix 1.1 for results of the analyses. Legend and key to symbols for this Figure and Figures 4-13 and 15-17 are contained in Table 2.

MacGillivray, 1974c). Gilpin (1899) reported that the oil shale occurs as a number of beds 2-10 ft. (0.6-3.0 m) thick which extend east-west for several miles.

Attempts at mining the oil shale and extraction of shale oil have had an uncertain history. The occurrence was mined about 1890 from a shaft sunk in a belt of black shale to a depth of 20 m and a distillation plant was erected in an attempt to exploit the shale (Neville, 1891; Gilpin, 1900; Ells, 1909; Drummond, 1918). Remains of the workings, located 350 m west of the lake along a small brook, still exist. The plant, whose existence was doubted by Drummond (1918), was reported to have operated for only a short period of time (Ells, 1909). Upon visiting the site, Drummond (1918) observed that attempts were made to extract oil from coal (obtained from the Sydney River-Reserve coal resource) rather than the local oil shale.

Recent oil shale resource evaluation work in the area has been carried out by Mazerolle and MacGillivray (1974c) and Potter (1977). Mazerolle and MacGillivray (1974c) reported the occurrence of a 1 m thick band of oil shale exposed along the road cut. Potter (1977) investigated the strata through two diamond-drill holes (Fig. 3) located near the workings, 400 m west of the western end of McAdams Lake. The holes cored a thin seam (less than 30 cm thick) of anthracite coal (Potter, 1977) but no oil shale was intersected.

The authors examined strata (500 m thick) exposed along the road cut near McAdams Lake

and the sections cored in the two drillholes. The road cut section occurs at the crest of a southwesterly-plunging anticline and comprises dark green-grey siltstone, sandstone and conglomerate. Nine thin (7.5-60 cm thick) interbeds of dark grey to black laminated silty shale occur in the basal 100 m of the roadcut section. The 'coal' cored in the drillholes is 30 cm thick and is better described as coaly shale; it is lithologically similar to, and probably continuous with, shales exposed in the road cut. Rock-Eval pyrolysis of three shale samples obtained from the road cut section (sample locations shown in Fig. 3) shows them to: (1) be thermally mature (within the oil window), (2) contain 2.5-18.5% organic carbon and (3) produce hydrocarbon yields of 1-20 l/t (Appendix 1.1). Hydrogen indices, derived from the Rock-Eval data, also indicate that the organic component of the shale is derived from carbonaceous (humic), rather than algal, remains. Analyses by Chevron Canada Resources Ltd. (Pounder, 1979; Appendix 1.1) of a sample from NSDME borehole ML-2 (Fig. 3) gave similar results: 3.0% organic carbon, comprising mainly vitrinite, inertinite and undifferentiated organic matter at a mature stage of thermal diagenesis. Vitrinite reflectance measurements of coal cored in the two holes also support a mature rank level (0.86-1.06% mean Ro, high volatile A bituminous; Avery and Hacquebard, 1977).

The zone containing the shale appears to be continuous from the road cut along the crest of the anticline to the drillhole sections, a distance of 1.0 km. However, the shale offers little or no potential as an oil shale resource due to its low oil yield. Oil yields of the rocks are below the lower limit for an oil shale and composition of the organic component suggests that the rocks are better considered as carbonaceous or coaly shale.

References Cited: McAdams Lake Area

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Forbes, W. H., Kasper, A. E., Donohoe, H. V. and Wallace, P. I., 1979.

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Keppie, J. D., 1979.

Mazerolle, G. J. and MacGillivray, G., 1974c.

McGregor, D. C., 1977.

Murray, B. C., 1960.

Neville, P., 1891.

Potter, W., 1977.

Pounder, D., 1979.

Additional Selected References: McAdams Lake Area

Bell, W. A., 1958.

Fletcher, H., 1903.

Macauley, G., 1981.

Naylor, R. D. and Smith, W. D., 1988a.

Naylor, R. D., Smith, W. D. and Conrod, D. J., 1987.

Shea, F. S., 1977.

LATE DEVONIAN - EARLY MISSISSIPPIAN (FAMENNIAN - TOURNAISIAN)

The following section includes those areas containing late Devonian - early Mississippian strata that have been reported to contain oil shale. The strata of this age belong to the Horton Group and those areas examined include the Antigonish Basin, Cape St. Lawrence area, Minas Basin and Scotsburn Anticline.

Oil shale, bituminous shale and/or bituminous limestone have also been reported from Horton Group strata in Margaree Valley, Lake Ainslie and the Strait of Canso area (Fletcher, 1885; Ells, 1909; Bell, 1958; Cote, 1960; Murray, 1960; Reardon, 1985). However, samples obtained from the section at Mabou River and Lake Ainslie by Potter (1977) showed little or no hydrocarbon yield and shale examined by the authors at Gallant River and Judique Intervale Brook (Margaree Valley area) are silty and lack organic matter.

Antigonish Basin (Big Marsh, Beaver Settlement)

Stratigraphy, Age and Depositional Environment

Oil shale was first reported in the Antigonish Basin by How (1868; Table 1) within late Devonian - early Mississippian strata (Benson, 1970, 1974; McGregor, 1971; Boehner and Giles, 1982). The strata, assigned to the South Lake Creek Formation of the Horton Group by Murray (1960), underlie an area of approximately 175 km^2 and occur in the northwestern part of the Antigonish Basin (Fig. 4). The South Lake Creek Formation is overlain and underlain by predominantly red alluvial fan deposits of the Ogden Brook and Rights River Formations, respectively. The South Lake Creek Formation is a sequence of predominantly brown sandstone with red and grey conglomerate and mudstone, and contains grey to black oil shale and thin impure coal (Murray, 1960). The formation was calculated by the authors to be 1230 m thick using Murray's (1960) data and at least 500-600 m thick by Prime (1987) based on his field studies.

On the basis of texture (grain size) and colour, Murray (1960) divided the formation into three conformable members (in descending order): Graham Brook, Big Marsh and Fairmont. The Graham Brook and Fairmont Members comprise red and grey sandstone interbedded with conglomerate, siltstone and shale. The Big Marsh Member, estimated to be 150 m thick (Murray, 1960; Potter, 1976a), is dominated by grey to black carbonaceous and bituminous shale (oil shale) with minor cross-laminated, medium grained brown sandstone and thin beds of impure coal. Recognition of this three-fold subdivision of the formation appears to depend on the presence of the intermediate oil shale-bearing member. Prime (1987) was unable to apply this subdivision to the formation on a basin-wide scale due in part to the difficulty of distinguishing between the upper and lower members, especially where outcrop and subsurface data are limited. In addition, Prime (1987) suggested that the three members may not have been deposited in succession everywhere within the basin and that the coarse grained deposits may have been, in part, lateral facies equivalents to the oil shales. The formation has been interpreted by Prime (1987) as a fluvial-lacustrine deposit.

Oil Shale

Two types of black oil shale are reported in the Big Marsh Member (Ells, 1909, 1910; Murray, 1960). The first type gives a low hydrocarbon yield and is the most common. It is described as "thin-slitting (fissile) carbonaceous shale" (Ells, 1910) with abundant remains of the paleoniscoid fish *Elonichthys browni* (Jackson). The second type is markedly less fissile, gives higher yields, and is described by How (1868) and Ells (1909) as a pyrobituminous cannel shale with a 'curly' texture and conchoidal fracture. These oil shales have been equated with those of the Albert Formation, southeastern New Brunswick, and with the black shale of the Horton Bluffs Formation, Hants and Kings Counties, on the basis of similar or identical species of fossil fish (Murray, 1960) and on stratigraphic position and lithologic similarity (Macauley and Ball, 1984).

Mazerolle and MacGillivray (1974a, 1974b) and Potter (1976a) outlined two zones of oil shale through surface mapping and diamond-drilling at Beaver Settlement and Big Marsh (Fig. 4). The Beaver Settlement zone, exposed near the mouth of Livingstone Brook, averages 61.6 m thick in two drillholes (DDH 2, 4). The zone extends along strike for at least 1.6 km and dips northerly at 30-35°. The eastern, western and northern limits of the zone are unknown. The Big Marsh zone, exposed along Wallace Brook/South Lake Creek, averages 117.5 m thick in three drillholes (DDH 5,

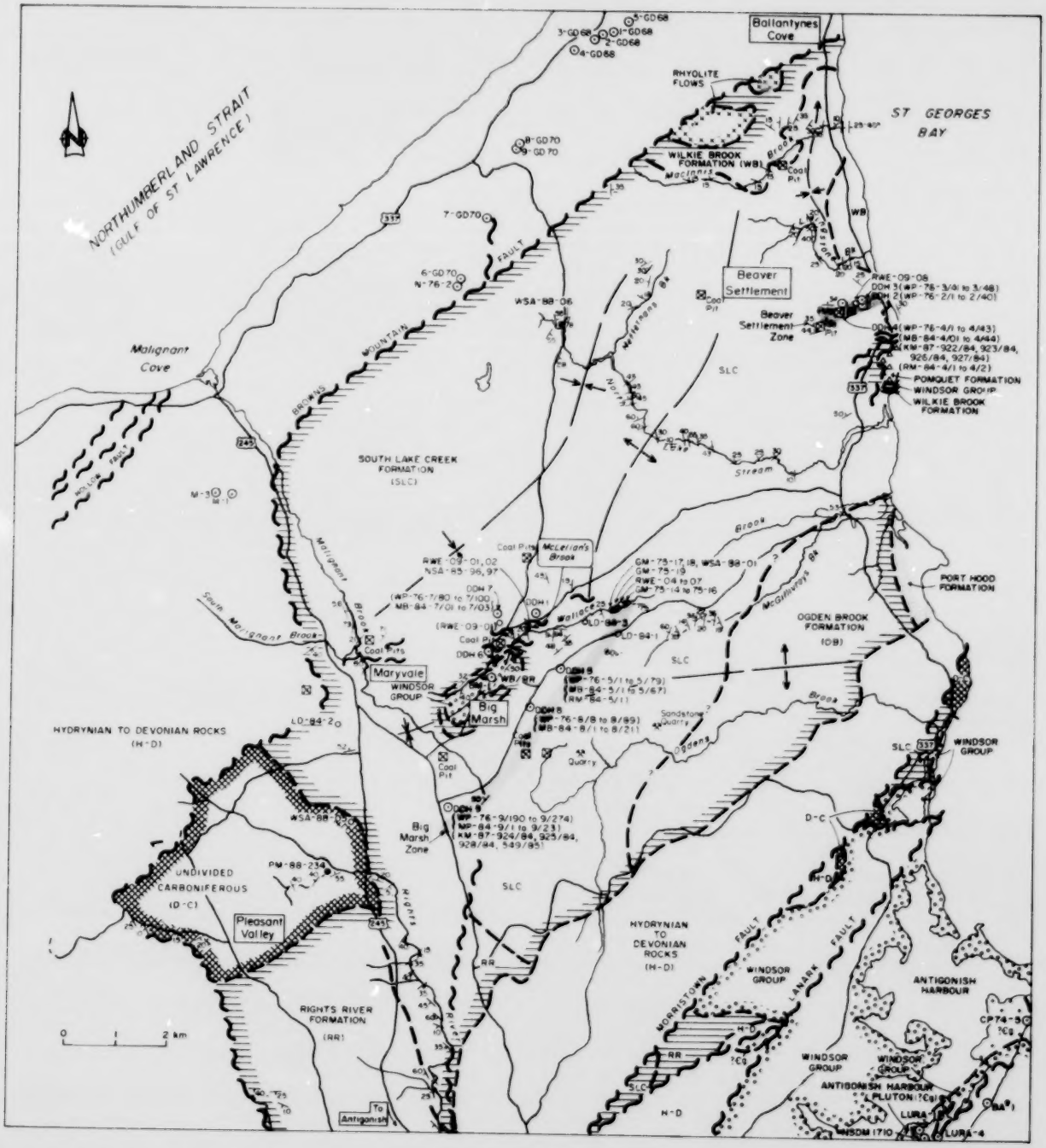

Figure 4. Geology of the northwestern part of Antigonish Basin (after Fletcher and Faribault, 1893; Murray, 1960; Benson, 1970, 1973; Mazerolle and MacGillivray, 1974a, 1974b; Giles, 1980; Boehner and Giles, 1982; Prime, 1987) showing the location of drillholes, and drill core and outcrop samples taken for testing. Bracketed sample numbers indicate drill core samples. See Appendix 1.2a-j for results of the analyses.

8, 9). The zone extends along strike for a distance of 4.8 km and dips to the northwest at 30-35°. The eastern limit of the zone is at Wallace Brook but the western limit is unknown. The zone probably extends as far west as the upper reaches of Rights River where oil shale is exposed (Murray, 1960) an additional 1.5 km beyond DDH 9 (see Fig. 4).

Oil shale occurrences in pits and streams, and in drillholes elsewhere in the basin, may represent extensions of these zones. Oil shale occurs in pits dug along the most northwesterly tributary of Wallace Brook (Mazerolle and MacGillivray, 1974c), in the vicinity of Maryvale (Malignant Brook) and Pleasant Valley (Drummond, 1918). Pits dug for coal in the Beaver Settlement area, identified on the maps of Fletcher and Faribault (1893), probably intersected oil shale as well (Murray, 1960). Oil shale is also reported as outcrop along McLellans (Black Shale) Brook and as extensive float east of Big Marsh (Mazerolle and MacGillivray, 1974a, 1974b, 1974c). A drillhole north of Wallace Brook (DDH 7: Potter, 1976a; Macauley and Ball, 1984) and holes drilled near Maryvale and Pleasant Valley in the early 1900s (Drummond, 1918) were also reported to have encountered oil shale. Beds of dark grey to black shale have also been reported in Horton Group strata in a road cut along the main highway 29 km east of Antigonish in the Monastery - Tracadie area (MacNeil, 1955; Berry, 1972).

Results of laboratory tests on shale sampled from Big Marsh and Beaver Settlement are summarized in Table 3 and are given in detail in Appendices 1.2a-1.2k. The analyses show that the oil shale is typically silicate-rich with only minor carbonate. Iron, aluminum and silicate minerals, comprising clays and quartz, account for over 90% of the inorganic component. Ammonium sulphate yields of 0-19.0 kg/t (avg. 11.7 kg/t) have been measured for samples from the Big Marsh zone. Oil yields of 0-55 litres per tonne of rock (l/t) (avg. 14.2 l/t) have been obtained at Big Marsh and yields of 0-58.9 l/t (avg. 19.1 l/t) have been obtained at Beaver Settlement. The organic matter, which accounts for 1.4-12.1% of the shales, is at a mature stage of thermal diagenesis and comprises algal detritus with minor amounts of humic material, spores and algal bodies (Kalkreuth and Macauley, 1986, 1987). The shale at Beaver Settlement is richer in well-preserved organic matter of algal origin than the Big Marsh shale. This accounts for its higher hydrogen indices and oil yield.

A total resource of 738 million tonnes of oil shale, to a depth of 400 m, is estimated for the two zones (Table 4). At Big Marsh 668.4 million tonnes of oil shale, with average yields of 14.2 l/t, give 9500 million litres (66.4 million barrels) of shale oil *in situ*. At Beaver Settlement 69.6 million tonnes of oil shale, with average yields of 19.1 l/t, give 1333 million litres (9.3 million barrels) of shale oil *in situ*.

Previous estimates of available resources in the Antigonish Basin were placed at 739 million tonnes of oil shale and 142.5 million barrels of shale oil *in situ* by Rockwell and Munroe (1984). Rockwell and Munroe's estimates, however, are considered to be unrealistic as their calculations are based on an average yield of 35 l/t. A 60 m deep shaft, driven around 1865 in the Big Marsh area to reach a section of the rich cannel/massive shale, was the only significant attempt at establishing an oil shale industry in the area (Ells, 1909).

References Cited: Antigonish Basin

Benson, D. G., 1970, 1973, 1974.

Berry, C. G., 1972.

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Drummond, R., 1918.

Ells, R. W., 1909, 1910.

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McGregor, D. C., 1971.

Murray, B. C., 1960.

Potter, W., 1976a.

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Table 3. *Summary of laboratory test results for oil shale sampled from Big Marsh and Beaver Settlement (detailed results in Appendices 1.2a-1.2j). n = number of analyses; TOC = total organic carbon; Ro = vitrinite reflectance; m.m.f. = mineral matter free; EX = exinites; VIT = vitrinites; IN = inertinites; WFG = weekly fluorescing groundmass; IL = illites; MLC = mixed layer clays; K/CH = kaolinite/chlorite; QU = quartz; FS = feldspars; SI = siderite; PY = pyrite; OTH = other minerals; TMAX = temperature of maximum hydrocarbon generation.*

ANALYSIS		BIG MARSH	BEAVER SETTLEMENT
Oil Yield (l/t)	Range	0-54.9	0-58.9
	Average	14.2	19.1
	n	422 (33 outcrop, 389 core)	136 (1 outcrop, 135 core)
	Anomalies	1 sample: 114.8 l/t	
TOC (WT%)	Range	1.4-12.1	2.7-11.6
	n	122 (8 outcrop, 114 core)	44 (core samples)
	Anomalies	1 sample: 67.4 wt%	-
Hydrogen Index (H.I.)	Range	111-577	243-679
	n	120 (6 outcrop, 114 core)	44 (core samples)
	Anomalies	5 samples: 31, 35, 64, 71, 1700	-
Ro (mean)	Range	0.62-1.31	0.44-0.59
	n	4 (core samples)	4 (core samples)
Average Petrography (% m.m.f.)	EX	16	27.5
	VIT	5.5	0.5
	IN	5.5	0.5
	WFG	73	71.5
	n	6 (2 outcrop, 4 core)	4 (core samples)
Inorganic Geochem	Fe	11	8
	Al	22	21
	Si	58	63
	n	1 (core sample)	2 (core samples)
Mineralogy* (Range and mean; in %)	IL	7-15; mean = 11	10-13; mean = 11
	MLC	9-22; mean = 13	8-15; mean = 11
	K/CH	6-33; mean = 12	11-23; mean = 16
	QU	38-69; mean = 49	47-58; mean = 63
	FS	0-7; mean = 4	3-9; mean = 5
	SI	0-18; mean = 5	0-5; mean = 2
	PY	0-4; mean = 1	0-1; mean = <1
	OTH	0-10; mean = 5	0-5; mean = 2
	n	47 (core samples)	11 (core samples)
$NaSO_4$ Yield (Kg/t)	Range	0-19.0	-
	Average	11.7	-
	n	6 (5 outcrop, 1 underground)	-
TMAX (°C)	Range	431-456	443-452
	n	121 (7 outcrop, 114 core)	44 (core samples)
	Anomalies	2 samples: 425,487	-

**Source of mineralogy data is Macauley and Ball (1984). The mineral percentages represent relative peak heights obtained from X-ray diffraction diffractograms and are not absolute values. Semi-quantitative values for the minerals present can be obtained by multiplying Macauley and Ball's (1984) values by the intensity factor of the mineral (from Umpleby et al., 1978; Cook et al., 1975; and Piper, 1977). Application of intensity factors to the determination of mineral abundances is required in order to correct for differences in the diffraction ability of various minerals caused by differences in mass absorption. The intensity factors are calculated relative to the primary quartz peak which is assigned an intensity factor of 1.00. Intensity factors for commonly occurring minerals are: quartz (1.00), illite (4.00), montmorillonite/smectite (1.00), kaolinite/chlorite (2.00), albite (2.80), K-feldspar (4.30), calcite (1.65), dolomite (1.53), siderite (1.15), pyrite (2.30).*

Table 4. *Estimates of recoverable oil shale, to a depth of 400 m, from Big Marsh and Beaver Settlement (bbls = barrels).*

	BIG MARSH	BEAVER SETTLEMENT	TOTAL
Tonnes	668.4 x 10^6	69.6 x 10^6	738 x 10^6
Avg. Yield	14.2 l/t	19.1 l/t	14.7 l/t
Shale Oil *In Situ*			
litres	9500 x 10^6	1333 x 10^6	10,833 x 10^6
bbls	66.4 x 10^6	9.3 x 10^6	75.7 x 10^6

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MacNeil, D. J., 1947, 1948, 1952.

McMahon, P. G., in prep.

Naylor, R. D. and Smith, W. D., 1988a.

Naylor, R. D., Smith, W. D. and Conrod, D. J., 1987.

Potter, W., 1975, 1976a, 1977.

Robbins, B., 1969.

Shea, F. S., 1977.

Cape St. Lawrence Area

Stratigraphy, Age and Depositional Environment

Dark shale contained within the middle Horton (Strathlorne) formation of the Cape St. Lawrence area, northern Cape Breton Island (Fig. 5), was first regarded as possible as oil shale by Brooks and Maehl (1955; Table 1). The formation is estimated to be 610-1220 m thick by Neale (1964a) and, more typically, 100-400 m thick by Hamblin (1989); the great apparent thickness is attributed to thrust repetition (Hamblin, 1989). The formation comprises medium- to dark-grey shale, fissile siltstone, micaceous sandstone and quartz pebble conglomerate with numerous thin beds of grey limestone (some stromatolitic, oolitic or intraclastic breccias) and limy siltstone (Neale, 1963b, 1964a; Hamblin, 1989). Plant fragments including *Lepidodendropsis sigillarioides*, *Lepidodendropsis corrugata*, and *Aenimites acadica* Dawson, and paleoniscoid fish scales are common (Brooks and Maehl, 1955; Murray, 1960; Neale, 1963a, 1963b, 1964a, 1964b). A late Tournaisian age has been assigned to the strata by Utting (1988). The formation is in fault contact with, as well as conformably overlain and underlain by, predominantly red sandstone, conglomerate and siltstone sequences (Neale, 1963a, 1963b, 1964a; Hamblin, 1989) of the lower (Craignish) and upper (Ainslie) Horton formations. Locally, the formation is in fault contact with the Canso and Windsor Groups (Brooks and Maehl, 1955; Neale, 1964b). The stratigraphic position of the Cape St. Lawrence sequence correlates with the lower to lower-middle members of the Horton Bluff Formation, the Big Marsh Member of the South

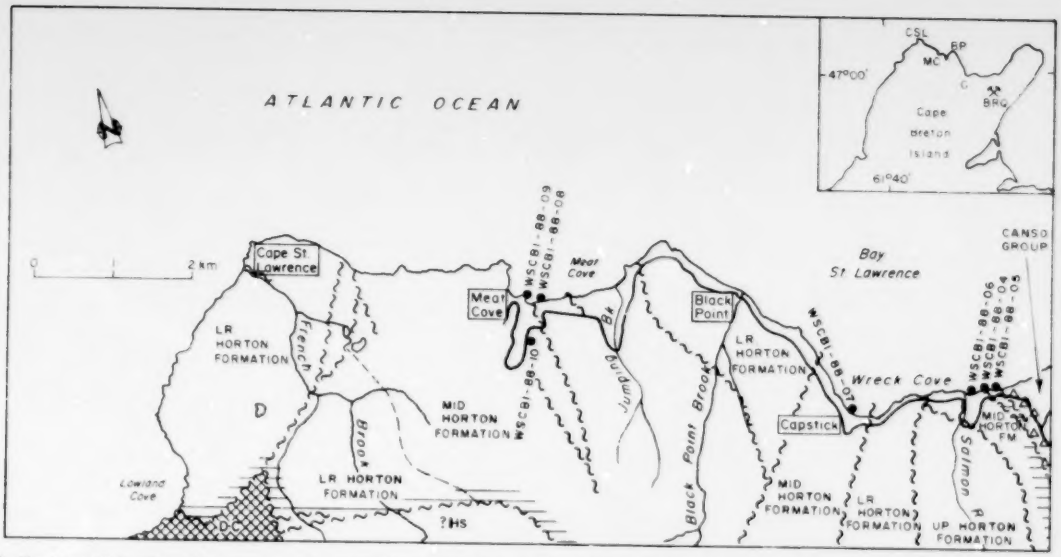

Figure 5. Geology of the Cape St. Lawrence area, northern Cape Breton Island (after Neale, 1963a, 1963b, 1964a, 1964b; Keppie, 1979) showing the location of outcrop samples taken for testing. Sample WSCBI-88-11 is located 3 km southeast of Salmon River in the Bay Road Quarry (inset: BRQ) along the road to Cape North. CLS = Cape St. Lawrence; MC = Meat Cove; BP = Black Point and C = Capstick. See Appendix 1.3 for results of the analyses.

Lake Creek Formation and the Frederick Brook Member of the Albert Formation (Utting, 1987, 1988).

A marine origin was proposed for the formation by Neale (1964a) on the basis of fossils from Jumping Brook tentatively identified by Brooks and Maehl (1955) as fenestrate bryozoans. However, a lacustrine depositional setting has been interpreted for these strata by Murray (1960) and Hamblin (1989) on the basis of sedimentology and facies relationships. The latter interpretation of the depositional setting is consistent with that of equivalent Horton strata elsewhere in Nova Scotia. Further, the identification by Utting (1988) of *Botryococcus sp.* in the samples analyzed for palynology supports a lacustrine interpretation.

Oil Shale

Dark grey to black shale possessing a waxy dark grey to brown streak and containing ostracodes and fish scales constitutes the oil shale lithology in the Cape St. Lawrence area. Such dark shale occurs as 0.1-3.0 m thick beds at Salmon River, Wreck Cove and Meat Cove (Fig. 5), and the nearby Bay Road Quarry. Rock-Eval pyrolysis of the shale (Appendix 1.3) shows organic carbon contents of 0.4-7.6 weight per cent and hydrocarbon yields of 0.3-29.0 l/t. The highest yields were obtained from the eastern part of the area, from shale exposed near the Horton-Canso contact at Salmon River and in the Bay Road Quarry. The organic matter is within the petroleum generation zone of thermal diagenesis (TMAX = 436-472°C:mature) and has hydrogen indices typical of humic material (HI = 21-112) or of a mixed assemblage comprising material of algal and humic sources (HI = 299-494).

Only shale from the Salmon River area, near the Horton-Canso fault contact, possesses sufficient yield to be considered oil shale. This shale was considered by Brooks and Maehl (1955) to be possible oil shale and designated as lean oil shale by W. A. Bell (pers. comm. to Brooks and Maehl, 1955) with yields not exceeding several gallons to the ton.

This shale and samples from elsewhere in the section may have acted as a local petroleum source rock. The petroliferous odour and staining in thin beds of vuggy limestone of the upper Windsor Group (Neale, 1963a, 1964b), in fault contact with the middle Horton formation, and the oil/tar seeps from Meat Cove (Mather, 1944) and at the mouth of Jumping Brook (Brooks and Maehl, 1955) may have been derived locally from the shale.

References Cited: Cape St. Lawrence Area

Brooks, D. B. and Maehl, R. H., 1955.

Hamblin, A. P., 1989.

Keppie, J. D., 1979.

Mather, K. F., 1944.

Murray, B. C., 1960.

Neale, E. R. W., 1963a, 1963b, 1964a, 1964b.

Utting, J., 1987, 1988.

Minas Basin

Stratigraphy, Age and Depositional Environment

Black and grey shale from the Horton Group at Horton Bluff in the Minas Basin has been reported as potential oil shale by Fletcher (1894) and Ells (1909, 1910; Table 1). In the Minas Basin, the Horton Group comprises the upper Cheverie and lower Horton Bluff Formations (Bell, 1929). The Cheverie Formation, of late Tournaisian age, is 190 m thick and rests disconformably on the Horton Bluff Formation (Bell, 1960). The Horton Bluff Formation, also of Tournaisian age, is 540 m thick and rests with angular unconformity on, or is in fault contact with, basement rocks (Martel and Gibling, 1988).

The Horton Bluff Formation has been subdivided into upper, middle and lower members by Bell (1929). It is correlated with the Albert Formation of New Brunswick and the Strathlorne Formation of Cape Breton Island on the basis of similar fish and plant remains (Murray, 1960) and palynology (Varma, 1969). A fluvio-lacustrine origin for the formation has been proposed by Bell (1929), Murray (1960), and Martel and Gibling (1987, 1988). The middle member, 340 m thick, contains the black and grey shale beds of interest (Fletcher, 1894; Ells, 1909, 1910; Macauley, 1981), as well as minor dolostone and limestone (Ferguson, 1983; Moore and Ferguson, 1986). The middle member is overlain by interbedded shale, siltstone and sandstone and is underlain by interbedded siltstone, sandstone, conglomerate and breccia. Minor, thin coal seams are also reported in the Horton Group (undifferentiated) at Gore (Fletcher, 1907; Hacquebard and Donaldson, 1970; Avery, 1986), some 40 km east of Horton Bluff.

Oil Shale

Thick bands of shale belonging to the middle member of the Horton Bluff Formation exposed at Horton Bluff (Fig. 6) have been described as "blackish, shiny and bituminous and similar to those of Big Marsh and East Bay which burn freely and have been mined for coal" (Fletcher, 1894). Fletcher (1894) also described the occurrence of bluish-grey, argillaceous shale yielding the odour of petroleum encountered at a depth of 100 m in a borehole near the Hants - Kings County border. A bed of oil shale 3-4 m thick has also been reported at a depth of 240 m in a borehole near Hantsport (Ells, 1909, 1910). Several thin bands of oil shale were also reported by earlier workers to be exposed at low tide in the Cheverie and Walton areas (Ells, 1910). Samples of oil shale from the Hantsport borehole were not available for testing by Ells (1910) and the occurrence at Cheverie - Walton could not be located by Ells (1910).

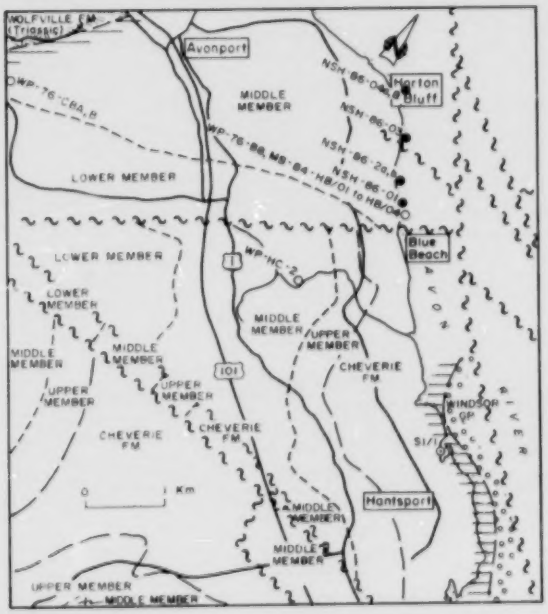

Figure 6. Geology of the Horton Bluff area, Minas Basin (after Ferguson, 1983; Moore and Ferguson, 1986) showing the location of outcrop samples taken for testing. See Appendix 1.4a and 1.4b for results of the analyses.

The thick beds of black shale have been considered by Fletcher (1903), Ells (1909) and Bell (1958) to be source beds for the oil, bitumen and albertite (a solid hydrocarbon) found in the overlying Windsor Group. On Cheverie Brook, oil and bitumen occupy cavities and fissures in gypsum that overlies a thick black shale sequence (Fletcher, 1903; Ells, 1909). Similarly, Bell (1958)

reported that drilling of gypsum deposits in the Mount Denson area (3 km southeast of Hantsport) in 1957 encountered a 34 cm bed of bituminous shale with albertite and a 60 cm bed of albertite-bearing, black, bituminous, calcareous shale within anhydrite. The drillhole passed through the anhydrite into strata presumably belonging to the Cheverie Formation.

For this project, samples of black shale belonging to the middle member were obtained from two areas, the Horton Bluff-Blue Beach section (Fig. 6) and drillhole S1/4 near Upper Falmouth (Fig. 7), and analyzed by Rock-Eval pyrolysis. At Horton Bluff-Blue Beach, the shale is thermally mature (TMAX values of 436-460° C), contains less than 1% organic carbon and gives hydrocarbon yields of only 5 l/t or less (Appendix 1.4a). Similar results for the same shale have also been reported by Potter (1977) and Macauley and Ball (1984) (Appendix 1.4a). Potter (1977) examined the black shale section at Horton Bluff-Blue Beach as well as exposures in Curry Brook and Hurd Creek (Fig. 6) and at Cheverie, Mutton Cove, and East Noel River. All shale horizons were sampled by Potter (1977) and those thought to have potential oil yield were tested at the Nova Scotia Technical College (now the Technical University of Nova Scotia) retort in Halifax. Only trace amounts of hydrocarbons were obtained from the Curry Brook samples and the remainder gave no yield. Macauley and Ball (1984) traversed the Horton Bluff - Blue Beach section as well and they obtained five samples (Fig. 6) for analysis by Rock-Eval pyrolysis. Results from this testing also showed that the shale has little or no hydrocarbon yield, low hydrogen indices and variable TMAX values. Three of the samples had TMAX values greater than 480°C, suggesting thermal overmaturity. Macauley and Ball (1984) also conducted mineralogical analyses on the shale, using X-ray diffraction, which showed it to be silicate-rich (quartz, clays) with minor carbonate (calcite, dolomite, siderite; Appendix 1.4b). The organic component of the Horton Bluff shale was considered to be carbonaceous rather than bituminous (Ells, 1910) and our Rock-Eval data tend to support that conclusion.

At Upper Falmouth (Fig. 7), the middle member cored in drillhole S1/4 is about 160 m thick (Quarch *et al.*, 1979; Moore and Ferguson, 1986) and comprises a 45 m thick, dark grey, silty and micaceous shale sequence underlain by 115 m of sandstone with minor siltstone and thin beds (0.10-0.50 m thick) of organic-rich (in part coaly) shale. Rock-Eval pyrolysis of samples of the shale sequences and organic-rich to coaly shale (Appendix 1.4c) shows substantially higher levels of organic carbon and hydrocarbon yield than shale exposed at the Horton Bluff section. The Falmouth shale contains 2.7-31.6 weight per cent organic carbon at an immature stage of thermal diagenesis (TMAX: 433-439°C) and produces 1.7-28.3 litres of hydrocarbon per tonne of rock upon distillation. The hydrogen indices (81-180) indicate that the organic carbon is of humic, rather than algal, origin similar to shale of the Horton Bluff section.

Portions of the middle member of the Horton Bluff Formation at Upper Falmouth show elevated organic carbon contents and hydrocarbon yields such that they are considered to be oil shale. However, since the liquid products are derived from a humic rather than algal source (and therefore represent a poor quality refinery feedstock) and because those beds recognized as producing sufficient yield are less than 0.5 m thick, this oil shale is not considered to represent significant resources. Nonetheless, development of organic-rich sections within the middle member suggests that favourable environmental conditions for oil shale development may have existed elsewhere within the basin during deposition of the middle member. The organic-rich sections may have acted as a source rock for the petroleum occurrences within the overlying Windsor Group and recognition of sites containing such sections may have significant implications for future petroleum exploration within the Minas Basin.

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Bell, W. A., 1929, 1958, 1960.

Ells, R. W., 1909, 1910.

Ferguson, S. A., 1983.

Fletcher, H., 1894, 1903, 1907.

Hacquebard, P. A. and Donaldson, J. R., 1970.

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Macauley, G. and Ball, F. D., 1984.

Martel, T. and Gibling, M. R., 1987, 1988.

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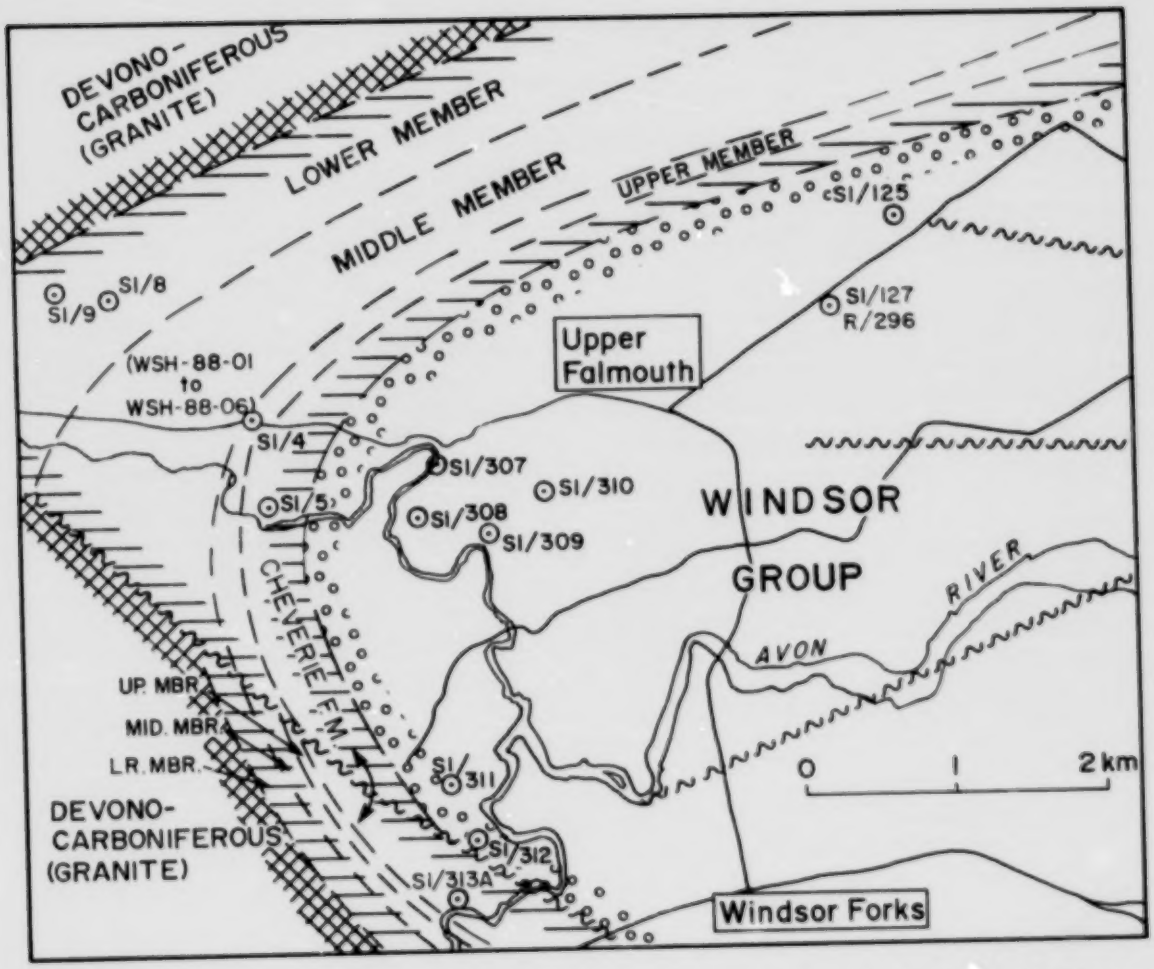

Figure 7. Geology of the Upper Falmouth area, Minas Basin (after Moore and Ferguson, 1986), showing the locations of drillholes and drill core samples taken for testing. See Appendix 1.4c for results of the analyses.

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Quarch, H., Rikeit, K. and Ryan, R., 1979.

Varma, C. P., 1969.

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Scotsburn Anticline

Stratigraphy, Age and Depositional Environment

Reports of oil shale within strata of the Scotsburn Anticline (Fig. 8) were first made by

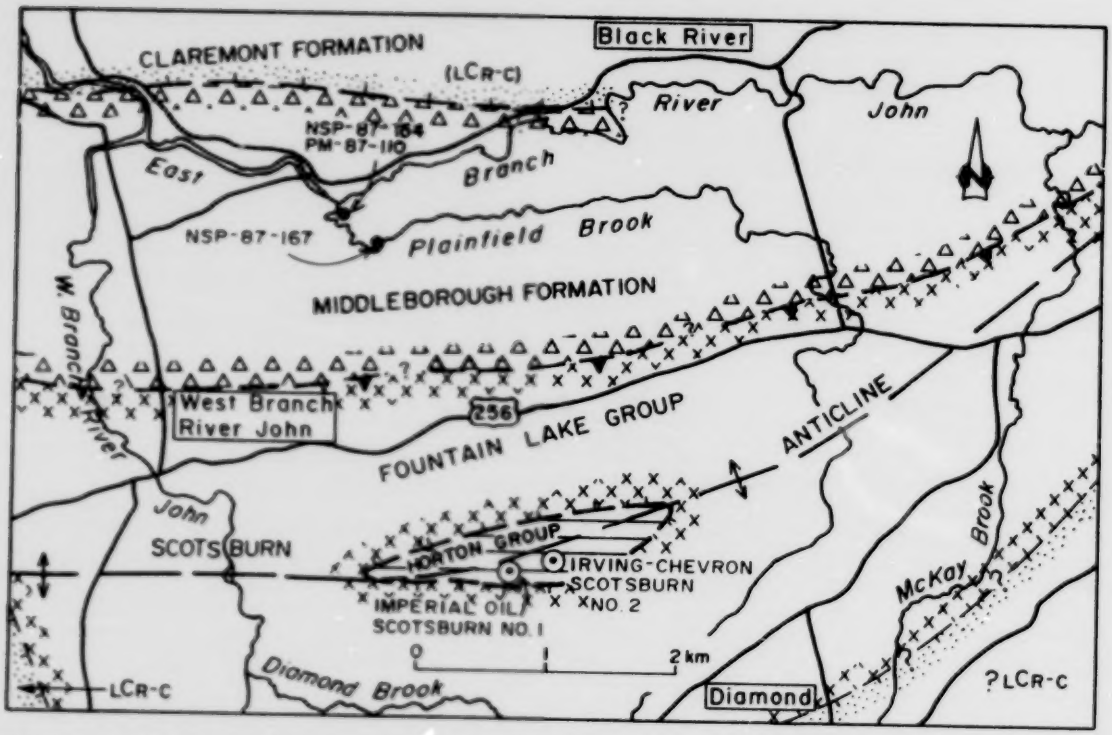

Figure 8. Geology of the Scotsburn Anticline (after Ryan et al., 1988 and modified after Donohoe and Wallace, 1982d) showing the location of drillholes and outcrop samples taken for testing. See Appendix 1.5a and 1.5b for results of the analyses.

Stewart *et al.* (1932; Table 1). The rocks of the Scotsburn Anticline were assigned to the River John Group/Series by Olsson and Fournier (1944), West (1944a), and Bell (1958), and the Diamond Brook Formation (Fountain Lake Group) by Keppie (1979) and Donohoe and Wallace (1982d). Ryan *et al.* (1988), based on recent field mapping and palynological analyses of rocks in this area, have assigned the strata to the Horton Group which unconformably overlies the middle Devonian Fountain Lake Group. Spore assemblages recovered from the Horton strata are typical of the Horton Group elsewhere and are indicative of a non-marine environment of deposition (Irving - Chevron, 1981). Palynological analyses (Irving-Chevron, 1981; Ryan *et al.*, 1988) confirmed the Horton assignment by defining a middle Devonian to Tournaisian age. The Horton Group and Fountain Lake Group sections have been thrust over the younger Middleborough Formation (Canso Group) which is situated to the north of the anticlinal axis (Ryan *et al.*, 1988).

Oil Shale

An exploration hole (Imperial Oil Scotsburn No. 1), drilled for petroleum at the crest of the anticline, reported a 1980 ft. (603.5 m) thick section of interbedded sandstone, shale and volcanics with minor dark grey oil-bearing limestone and three beds of black oil shale (Stewart *et al.*, 1932). The oil shale beds were intersected in the upper part of the section assigned to the Horton Group at depths of 415-420 ft. (126.5-128 m), 640-650 ft. (195-198 m), and 845-847 ft. (257.5-258 m). At 195 m the shale is finely laminated and at 257.5 m it contains fish remains (Stewart *et al.*, 1932). Subsequent deeper drilling to 2638 m (Irving-Chevron Scotsburn No. 2), situated 300 m east of the earlier hole, reported grey to dark shale, which is locally carbonaceous and contains moderate to abundant amounts of coal fragments (Irving - Chevron, 1981) rather than oil shale.

The sequence cored in the two exploration drillholes is not exposed at surface (Bell, 1958). However, solid hydrocarbon in the form of discontinuous fissure fills and intergranular pore fillings occurs in local sandstone outcrops (Olsson and Fournier, 1944; West, 1944a). The solid hydrocarbon-bearing sandstones are contained within the Fountain Lake Group and Middleborough Formation of Ryan *et al.* (1988). Bell (1958) considered the bituminous shale (oil

shale) and limestone reported in the Imperial Oil Scotsburn No. 1 section to be a possible source for the solid hydrocarbon contained within these beds.

Analyses of two samples of solid hydrocarbon (random reflectance measurements and insolubility in immersion oil) contained in sandstone of the Middleborough Formation confirmed the identification of albertite in one and wurtzilite in the other (P. McMahon and W. Kalkreuth, pers. comm., 1988) (Appendix 1.5a). The wurtzilite appears as a void-filling material constituting 20% by volume of the rock. When subjected to combustion testing, the wurtzilite is driven off as volatile matter and moisture (amounting to about 5 wt. % of the rock: Appendix 1.5b). Data from Rock-Eval pyrolysis (TMAX and H.I.) of the wurtzilite sample are consistent with a mature stage of thermal diagenesis and derivation from a predominantly algal source. The albertite appears as veinlets and fissure-filling material that may parallel or crosscut bedding.

The presence of oil shale within strata underlying the Scotsburn Anticline remains an enigma. Access to the oil shale-bearing section is only through the sub-surface and our efforts in this project cannot confirm or refute earlier reports of oil shale nor provide any information on oil shale quality and extent. However, the presence and geochemistry of the solid hydrocarbons albertile and wurtzilite in yonger strata suggest that oil shale occurs within the section and that it contains organic matter of algal origin at a mature stage of thermal diagenesis. Because much of the petroleum generation potential would have been realized through the production of albertite and wurtzilite, it is doubtful that there is sufficient hydrocarbon potential remaining, and therefore potential resources, in these rocks.

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Irving - Chevron, 1981.

Keppie, J. D., 1979.

Olsson, A. A. and Fournier, F. L., 1944.

Ryan, R. J., Deal, A., Calder, J. H. and Boehner, R. C., 1988.

Stewart, J. S., Roliff, W. A. and Moore, E. S., 1932.

West, D. M., 1944a.

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EARLY PENNSYLVANIAN (WESTPHALIAN A)

The only reported occurrence of oil shale in strata of this age is within the Riversdale Group of the Richmond Basin. Potter (1977) examined Riversdale strata of the Port Hood coalfield exposed at Cape Linzee for potential oil shale but his results showed that the local shale yielded little or no hydrocarbon.

Richmond Basin

Stratigraphy, Age and Depositional Environment

The earliest reference to oil shale within strata of the Richmond Basin (Fig. 9) was made by Fletcher (1881; Table 1). The shale is contained within a sequence, estimated to be 5000 ft. (1500 m) thick by Mather *et al.* (1944), of black slaty shale, massive grey sandstone, conglomerate and thin beds of coal. The sequence has been included within the Riversdale Group by Mather *et al.* (1944), MacNeil (1948) and Weeks and Ferguson (1950) and the name Lennox Passage formation was informally proposed for it locally by Mather *et al.* (1944). Belt (1964, 1965) included the basal part of the Lennox Passage formation in the upper part of the Mabou Group (Subdivisions A-2 and B-2) and he included the upper, coal measures section in the Port Hood Formation. Belt's subdivision has not been adopted by recent workers; Keppie (1979) assigned the strata to the (undivided) Riversdale Group and considered it a stratigraphic equivalent to the Port Hood Formation.

Coal has been mined from seams at Richmond (Richmond/Little River Mine) from 1863 to 1878 (Fletcher, 1881), Sea Coal Bay in 1864-65 (How, 1869), and Whiteside - Coal Brook until 1940-42 (Collins, 1962). A total of 9100 tons (8273 tonnes) was recovered from two seams, the 3 foot and 4 foot seams, at the Richmond Mine (Fletcher, 1881), approximately 450 tons (410 tonnes) from a seam reported to be 4-7 ft. (1.2-2.1 m) thick at Sea Coal Bay (How, 1869), and 100 tons (91 tonnes) from a seam 3.3 ft. (1.0 m) thick at Whiteside - Coal Brook (Fletcher, 1881; Collins, 1962). The Richmond coal was considered to be of poorer grade than coal of post-Riversdale age by Weeks and Ferguson (1950) but How (1869) reported that the coal reacted similarly to Pictou Group coal.

Oil Shale

Lithologies considered to be oil shale by earlier workers included black shale and dark grey to black pelecypod-bearing shale. Localities where these lithologies occur include Port Malcolm, Richmond, Whiteside-Coal Brook, Sea Coal Bay, River Inhabitants, Point Tupper and Port Hawkesbury. At Richmond, Whiteside - Coal Brook and Sea Coal Bay the black shale is associated with coal (Fletcher, 1881, 1903). At Sea Coal Bay, a 48 ft. (14.6 m) thick bed of black shale overlying the coal seam and two beds averaging 11 ft. (3.4 m) thick each were recorded at 82 ft. (25.0 m) and 93 ft. (28.3 m) above the coal by Fletcher (1881). The shale beds contain *Naiadites sp.*, *Cythere sp.*, *Spirorbis sp.*, fish and plant remains.

Rock-Eval pyrolysis results (Appendix 1.6) for samples of dark grey to black pelecypod-bearing shale from Port Malcolm and Whiteside show that they contain 3-5% organic carbon. However, the organic matter in these rocks is at a mature stage of thermal diagenesis (within the oil window) and hydrocarbon yields of only 2.5-6.0 l/t were obtained. A thin bed (10 cm thick) of black silty shale sampled at Port Hawkesbury contains significant organic content, 4% organic carbon (Appendix 1.6), but it is thermally overmature and virtually no hydrocarbons are generated by pyrolysis. Results similar to these were reported by Potter (1977) who sampled exposures of black shale at River Inhabitants and Point Tupper for analysis of their hydrocarbon content using the Fischer Assay facilities at the Nova Scotia Technical College (now the Technical University of Nova Scotia). Analyses of the samples showed that only one sample (from Inhabitants Cove) had a trace of hydrocarbons (as gas).

A mature level of thermal diagenesis for Riversdale Group strata is supported by vitrinite reflectance measurements reported by Hacquebard and Donaldson (1970). Coal samples obtained by Hacquebard and Donaldson (1970) from the Richmond Mine and the Tidewater Co. Mine show reflectance data (Appendix 1.6) indicative of a mature stage of thermal diagenesis midway through the oil window, well within the range of petroleum generation.

The results of our studies, coupled with those of earlier workers in the Richmond Basin, failed

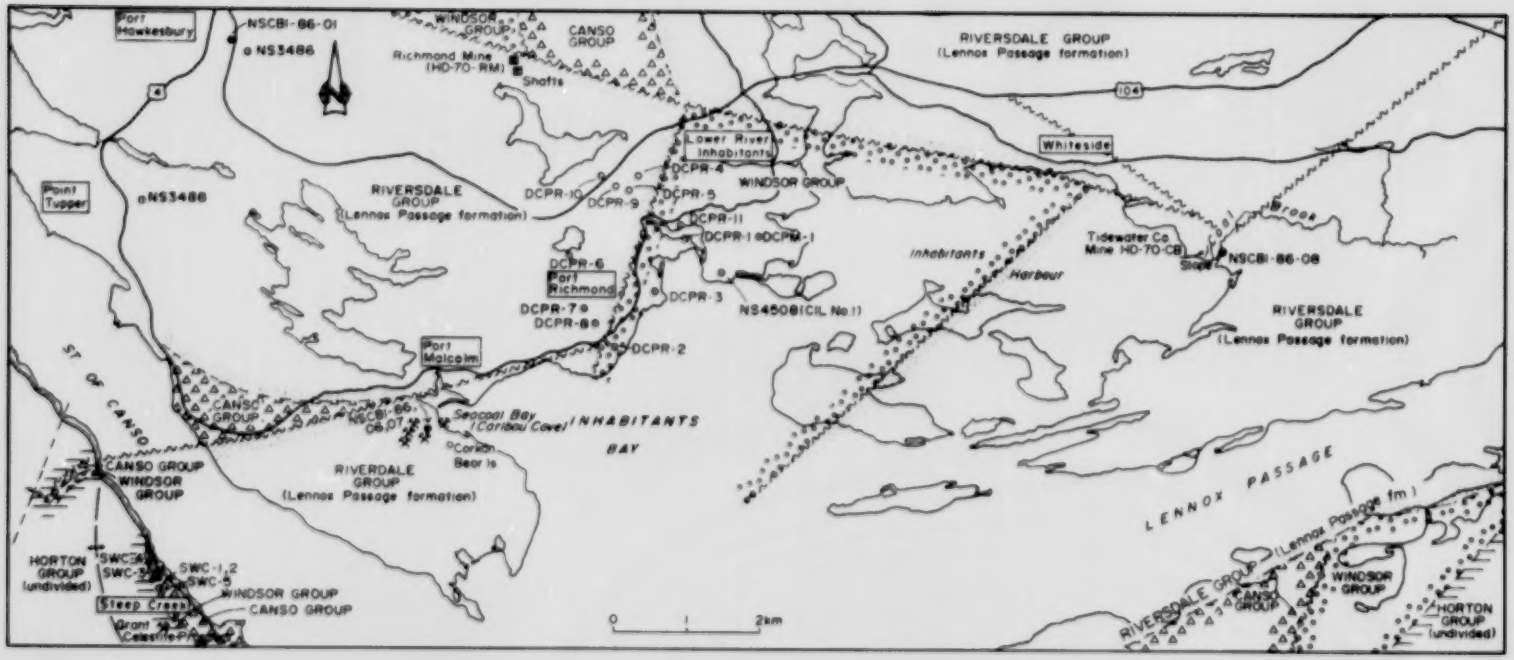

Figure 9. Geology of the Richmond Basin (after Weeks and Ferguson, 1950; Collins, 1953; FMC Mineral Development Department, 1971; The Dow Chemical Co. Minerals Department, 1972; Keppie, 1979) showing the location of drillholes, and mine and outcrop samples taken for testing. See Appendix 1.6 for results of the analyses.

to confirm the presence of rocks with sufficient hydrocarbon yield to warrant their classification as oil shale. Although levels of organic carbon of up to 5% obtained from some of the rocks are comparable to organic content of low grade oil shale (i.e. ca. 25 l/t) from the Albert Formation, New Brunswick, the hydrocarbon yields of these rocks are very low. The low hydrocarbon yields probably reflect earlier generation and expulsion of hydrocarbons from the rocks due to the onset of maturation (thermal diagenesis) and further suggest that the rocks acted as petroleum source rocks.

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FMC Mineral Development Department, 1971.

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Mather, K. F., Tullis, E. L. and Beck, C. W., 1944.

Potter, W., 1977.

The Dow Chemical Co. Minerals Department, 1972.

Weeks, L. J. and Ferguson, S. A., 1950.

Additional Selected References: Richmond Basin

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Potter, W., 1976a.

Shea, F. S., 1977.

Shea, F. S. and Wallace, J. D., 1962.

MIDDLE PENNSYLVANIAN (WESTPHALIAN A - C)

Two areas with strata of this age have been cited as containing oil shale by earlier workers. These areas are Cumberland Basin and Debert-Kemptown Basin.

Cumberland Basin

Stratigraphy, Age and Depositional Environment

The Cumberland Group in northwestern Nova Scotia comprises 2750 m of Pennsylvanian (Late Westphalian A - ?Westphalian D) coal-bearing strata which contain petroliferous limestone (Olsson and Fournier, 1944; Bell, 1958; Hacquebard and Donaldson, 1964; Rust *et al.*, 1984; Gibling, 1987; Ryan and Boehner, 1988) and minor, thin, petroliferous shale considered to be oil shale by Ells (1910; Table 1). The strata are contained within the Cumberland Basin (Fig. 10), in which the Athol Syncline and Minudie Anticline are the major structural features. The basin is bounded by the Cobequid Highlands to the southeast and the Caledonia Highlands to the northwest (Fig. 1).

The Cumberland Group is well exposed along the shore of Chignecto Bay from north of Joggins to Spicers Cove. The section was first described by Logan (1845) and later by Fletcher (1906, 1907), Duff and Walton (1973), Rust *et al.* (1984) and Gibling (1987). Recently, Ryan and Boehner (1988) and Ryan *et al.* (1988) have proposed formation names for the group and mapped their distribution within the basin. The formation names proposed are (in ascending order): Polly Brook, Joggins (Logan's Division 4), Springhill Mines (Logan's Division 3), Ragged Reef (Logan's Division 2 and 1), and Malagash (Fletcher's Divisions XI and X). The Joggins and Springhill Mines Formations contain coal seams (Ryan *et al.*, 1988) which were mined in the Joggins-Chignecto area and at Springhill, respectively (Copeland, 1959b). The Polly Brook Formation is considered to be a lateral equivalent to the Joggins and Springhill Mines Formations and possibly, in part, to the Ragged Reef Formation.

Oil Shale

Oil shale was first reported from the area by Ells (1910) and subsequently by Olsson and Fournier (1944). Lithologies reported as oil shale include petroliferous limestone, petroliferous and calcareous shale, and organic-rich shale; all occur within the Joggins and Springhill Mines Formations. These lithologies are commonly black and richly fossiliferous and vary from massive to fissile. Compacted shells of the bivalves *Naiadites* and *Cirvirimula* are abundant (Gibling, 1987) and give the beds a wavy lamination. Remains of ostracodes, conchostracans, annelid tests (*Spirorbis carbonarius* Dawson), mysidacid and diplopod arthropods, arachnids, fish fragments and algal material have also been reported (Olsson and Fournier, 1944; Copeland, 1957; Carroll *et al.*, 1972; Duff and Walton, 1973). A brackish, shallow lacustrine setting developed on an alluvial floodplain has been proposed by Gibling (1987) for these limestones. Petroliferous limestone and shale are known at Joggins, Maccan - Chignecto - Styles Brook (Fig. 10), Roslin, Springhill and Spicers Cove. Results of analytical testing of samples from these locations are given in Appendices 1.7a - 1.7d.

At Joggins, petroliferous limestone and petroliferous calcareous shale occur mainly within strata that underlie the Joggins - Queen seams. The beds are generally thin (10 cm thick or less), but locally (e.g. above the 40 Brine seam) attain a thickness of 1.7 m. X-ray diffraction (XRD) analysis shows that calcite constitutes up to 25% of the inorganic component of the calcareous shale. Rock-Eval pyrolysis data for samples of black shale, petroliferous shale and petroliferous limestone gave hydrocarbon yields of 0.7 - 22.2 l/t and total organic carbon (TOC) contents of 0.9-9.6% with the petroliferious calcareous shale showing the highest average yields (13.2 l/t; 2.1 l/t per 1% TOC). Combustion testing of a sample of petroliferous calareous shale gave a calorific value of 3927 BTU/lb. The organic component of the black shale is derived from a predominantly terrestrial source (humics: vitrinite, inertinite) whereas that of the petroliferous calcareous shale and limestone comprises a mixture of spores, algal material and detrital vitrinite as indicated by the hydrogen index and organic petrology data (Appendix 1.7). The organic matter in all of the samples tested showed an immature to near mature stage of thermal diagenesis based on the TMAX, thermal alteration index (T.A.I.) and vitrinite reflectance data. This stage of maturation is supported by analyses of 12 coal - coaly shale samples from the Joggins section which showed a high volatile C bituminous coal rank (equates to the onset of maturation; Tissot and Welte, 1984).

However, Calder *et al.* (1985) reported a high volatile B bituminous rank for the coals. Comparable reports on hydrocarbon quality and organic content for samples from this area are given by Chevron (1986).

At Maccan - Chignecto - Styles Brook, abundant petroliferous and pelecypod-bearing limestone and minor fissile organic-rich shale are contained in the strata above the Chignecto seam; the Chignecto seam represents the combined Kimberley - Forty Brine section of Joggins (Hacquebard and Donaldson, 1964). However, petroliferous limestone and organic-rich shale are absent from strata below the Chignecto seam. A redbed dominated section below the Chignecto seam, the Polly Brook Formation, is thought to correlate with the petroliferous limestone and shale package exposed at Joggins (J. Calder, pers. comm., 1987).

The limestone and organic-rich shale of Maccan-Chignecto-Styles Brook are up to 2.3 m thick and are associated with thin coal seams; the shale contains about 20% carbonate (mainly siderite). Rock-Eval results for this limestone-shale section are comparable to those obtained for the Joggins samples. The data indicate an organic carbon content of 0.5-10% for samples obtained from this area; the organic matter is approaching thermal maturity and it produces hydrocarbon yields of 0.1-20 l/t. Hydrogen indices of the samples (20-28 and 170-347) are typical of organic matter of terrestrial/humic origin and of a mixture of material derived from terrestrial and algal sources. Indices typical of the latter type represent 80% of the data. Combustion testing of organic-rich shale gave a calorific value of 1340 BTU/lb.

At Roslin (located 29 km east of the area shown in Fig. 10), exploratory drilling by the Nova Scotia Department of Mines and Energy (hole R-1) cored a 1.5-2.5 m thick section of petroliferous bivalve-bearing limestone. These strata have been assigned to the Pictou Group (Keppie, 1979). However, recent mapping and drilling indicate that the Roslin strata are lithologically similar to the lower part of the Joggins section (Calder, 1984; Joggins Formation). Although the stratigraphic position of the limestone is uncertain, it is thought to extend about 35 km from Maccan to Roslin. Rock-Eval pyrolysis results show that this petroliferous limestone is comparable to those studied elsewhere in the basin: they contain 1.3-4.3% (avg. 2.7%) organic carbon at an immature to near mature stage of thermal diagenesis, which produces hydrocarbon yields of 1.6-11.4 l/t (avg. 5.9 l/t) upon pyrolysis. Hydrogen indices obtained for the samples are consistent with organic matter of a terrestrial (humics) or mixed (spores, algal remains, humics) origin.

Within the Springhill coalfield at Springhill (located 4.3 km east of the area shown in Fig. 10), further drilling by the Nova Scotia Department of Mines and Energy to delineate the distribution of the Nos. 6 and 7 seams encountered a petroliferous bivalve-bearing limestone in drillhole SH95 (Naylor *et al.*, 1984). In the nearby drillhole, SH94, the limestone bed is 0.21 m thick, is lithologically similar to beds encountered elsewhere in the basin, and is included in probable Joggins Formation strata. Rock-Eval pyrolysis of the limestone from SH94 showed an organic carbon content of 1.2% at a mature stage of thermal diagenesis, producing a hydrocarbon yield of 1.4 l/t upon pyrolysis.

From Spicers Cove, samples of dark grey shale and coaly shale were obtained by Chevron (1986) from exposed strata assigned by Ryan *et al.* (1988) to the Ragged Reef Formation. Rock-Eval pyrolysis data show hydrocarbon yields of less than 5 l/t from the grey shale and yields of about 60 l/t from the coaly shale. The TMAX data indicate an immature stage of thermal diagenesis.

Except for the Joggins section, no other (accessible) geochemical data from the Cumberland Basin exist for comparison with our results. Hydrocarbon yield data for the Joggins section obtained by Chevron (1986) and Kalkreuth and Gibling (1987a; Appendix 1.7a) generally agree with our data. However, higher yields than we record are reported by these workers for the petroliferous bivale-bearing limestone (up to 28.5 l/t: Chevron, 1986, and up to 41.0 l/t: Kalkreuth and Gibling, 1987a, versus up to 22.2 l/t: our data).

From the results of our studies, and those of Chevron (1986) and Kalkreuth and Gibling (1987a), we conclude (on the basis of oil yield) that the only area of the Cumberland Basin known to contain oil shale grade lithologies is the Joggins section. In particular, the 1.7 m thick petroliferous and bivalve-bearing limestone overlying the 40 Brine seam shows the greatest hydrocarbon potential (2.2-41.0 l/t; avg. 19.5 l/t). The limestone bed and underlying coal are laterally continuous for at least 16 km from the coastal exposure to Maccan (Fig. 10) and together the limestone and coal may represent a resource of future interest. Yields of 32 l/t and 160 l/t have been obtained from the coal by Chevron (1986) and Kalkreuth and Gibling (1987a), respectively. High oil yields were obtained from the Spicers

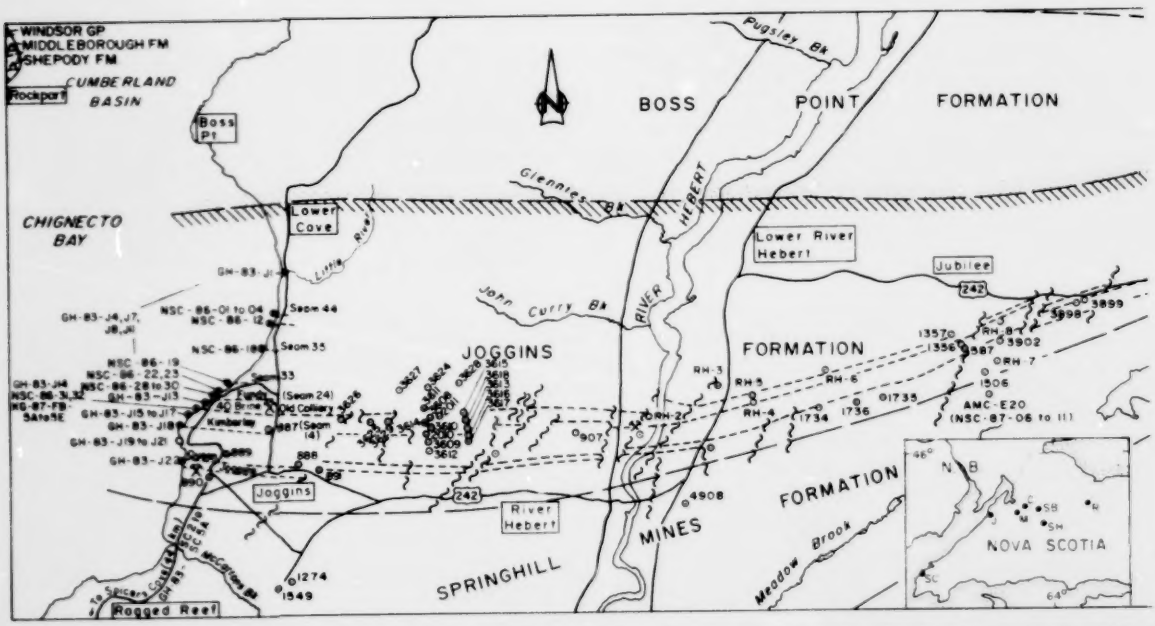

Figure 10. Geology of the southwestern part of the Cumberland Basin (Joggins - Chignecto coalfield) (after Copeland, 1959a; Duff and Walton, 1973; Gibling, 1987; Ryan and Boehner, 1988; Ryan et al., 1988) showing the location of drillholes, and drill core and outcrop samples taken for testing. Inset shows the location of Joggins (J), Maccan (M), Chignecto (C), Styles Brook (SB), Springhill (SH), Roslin (R) and Spicers Cove (SC). See Appendix 1.7a-d for results of the analyses.

Cove section by Chevron (1986); however, the samples were coaly shale and are not considered to be oil shale.

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Additional Selected References: Cumberland Basin

Donohoe, H. V. and Wallace, P. I., 1982a, 1982b.

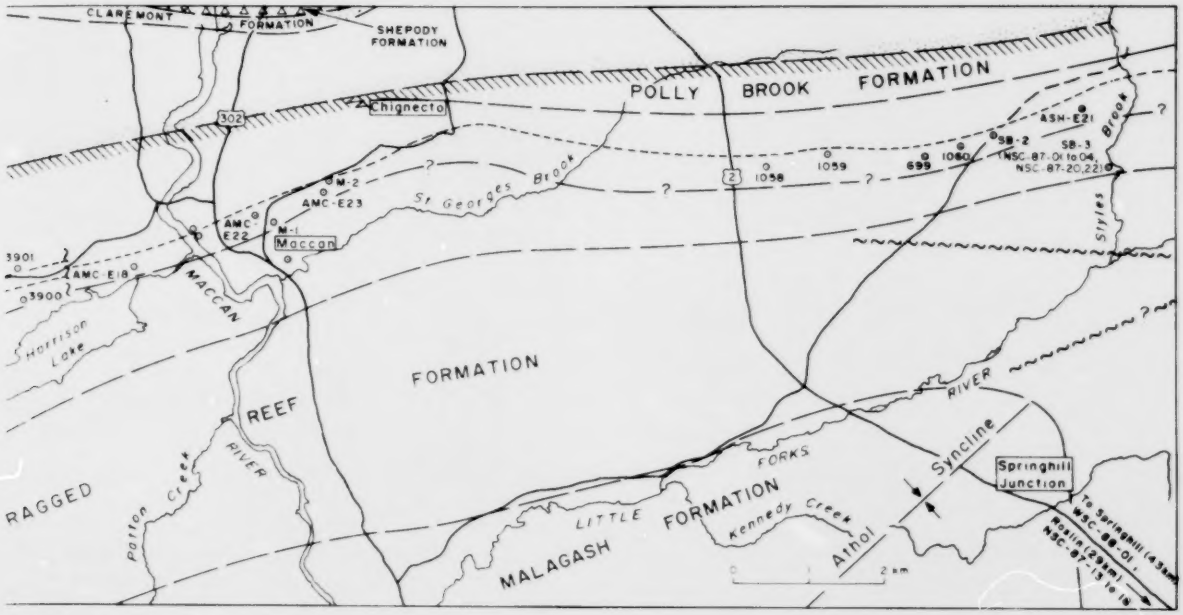

Figure 10. (continued)

Ferguson, L., 1975.

Goudge, M. G. and MacLeod, D. M., 1948.

Kerr, F. A., 1924.

Naylor, R. D., Smith, W. D. and Conrod, D. J., 1987.

Pickings, H. B., 1912.

Debert-Kemptown Basin

Stratigraphy, Age and Depositional Environment

Oil shale was first reported in Colchester County by Ells (1909; Table 1). The Debert-Kemptown Basin is a 200 km^2 elongate basin in Colchester County, bounded in the north by the Cobequid - Chedabucto Fault and the Cobequid Highlands and in the south by the Portapique Fault (Fig. 11), which contains the reported oil shale. Within this structurally complex basin (Wright, 1975; Naylor and Molyneaux, 1988) the Debert River Syncline is the major structural feature (Calder, 1985b) extending 40 km in the west and central areas from Folly Mountain to Kemptown. Strata of the basin have been assigned chiefly on the basis of age to the Cumberland and Pictou Groups by Bell (1958) and Stevenson (1958) and to the Pictou Group by Donohoe and Wallace (1982d). Calder and Naylor (1989) provisionally included these rocks with the Cumberland Group. An early Westphalian B age has been assigned to the rocks in the south and east areas of the basin and a Westphalian C age has been assigned to the rocks in the west part of the basin (palynology by S. Barss *in* Donohoe and Wallace, 1982d).

Lortie (1979) informally applied the name Delaney formation to these strata. He subdivided the Delaney formation into three members, McCallum, West Branch and Debert in ascending order, and mapped their distribution within the basin. The medial West Branch member is coal-bearing and contains red and green-grey shale, grey-white sandstone with plant fragments, yellow-brown conglomerate, and carbonaceous and moderately calcareous black shale associated with coal. Mining of the high volatile B bituminous coal has been carried out sporadically at Debert, Belmont (Chiganois River), Coal Mine Brook, and Kemptown (Stevenson, 1958; Calder, 1985b). Recent coal evaluation work has been carried out by Nova Scotia Department of Mines and Energy (drilling and mapping: 1975-1978) and by Suncor Resources Inc. (Gunn *et al.*, 1987; mapping). A lacustrine component for the member has been suggested by Calder (1985b) on the basis of bivalves found along West Branch North River in an exposure of fossiliferous siltstone.

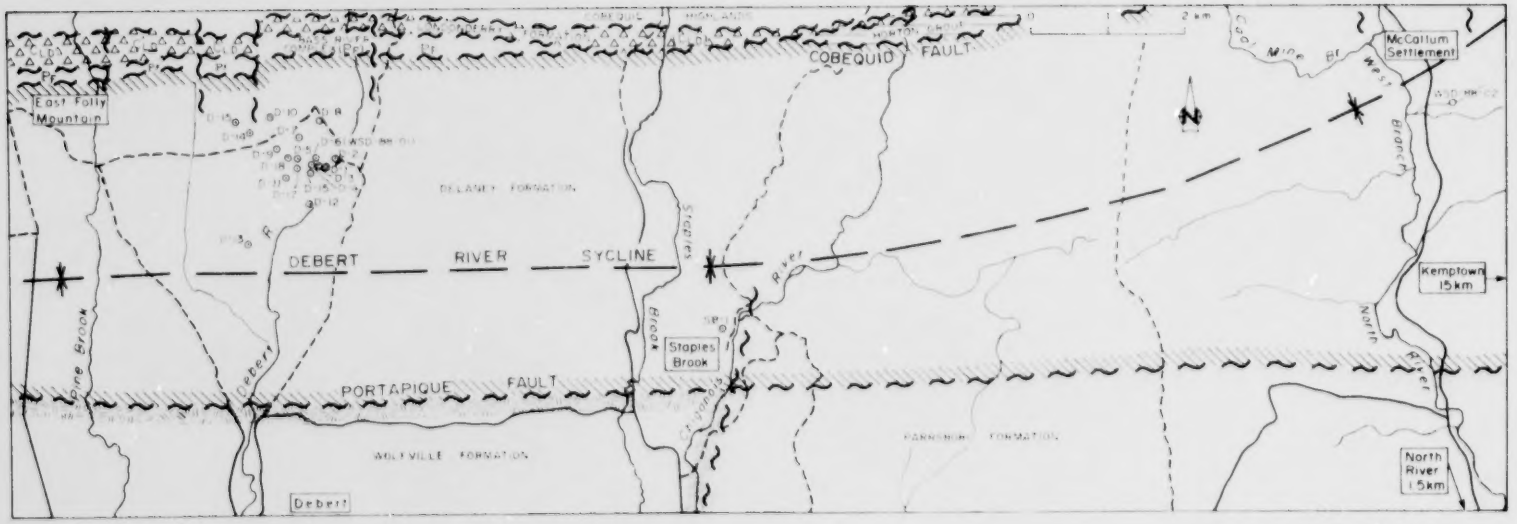

Figure 11. Geology of the Debert-Kemptown Basin (after Smith and Gillis, 1978; Lortie, 1979; Donohoe and Wallace, 1982d; Calder, 1985b; Naylor, 1988) showing the location of drillholes, and drill core and outcrop samples taken for testing. See Appendix 1.8 for results of the analyses.

Oil Shale

Beds of black shale in the region have received consideration by earlier workers as a possible source of oil through distillation (Ells, 1909, 1910; Clapp, 1915; Drummond, 1918; Flynn *et al.*, 1940; Potter, 1977). Ells (1909) reported "large volumes" of black shale at North River and Flynn *et al.* (1940) considered Colchester County to be rich in oil shale. Drummond (1918) considered the black shale to be comparable in quality to the stellarite oil shale of Stellarton because it "ignited and sustained a flame and had the same appearance as stellar coal". Smith (1975) reported a thin oil shale bed within the West Branch member cored in Nova Scotia Department of Mines and Energy drillhole section DDNSD-6 located 5 km north of Debert. Recent field mapping by Naylor (1988) also revealed exposures of thin beds of cannel shale (similar to those known from the Stellarton area) near McCallum Settlement.

The shale beds noted by Smith (1975) and Naylor (1988) were tested in this study by Rock-Eval pyrolysis and showed organic carbon contents of 18.4 and 23.5 weight per cent and hydrocarbon yields of 50.4 and 68.7 l/t, respectively. The organic component of these rocks is at a near mature to mature stage of thermal diagensis (TMAX = 432° and 448°C) and has hydrogen indices (HI = 353 and 371) typical of a mixed assemblage of organic matter (comprising alginite with vitrinite, bituminite or inertinite).

In contrast to our results, Ells (1910) stated that the local shale is carbonaceous and non-bituminous. Testing of the shale by Ells (1909) and Clapp (1915) showed no hydrocarbon yield. Testing of black shale samples from the North River area by Potter (1977) showed only gas yields of 500-1000 cubic feet per ton (15.6-31.2 m^3/tonne; Appendix 1.8).

The data of earlier workers show quite clearly that the large volume of black shale considered to be a possible source of oil does not represent potential oil shale resources. Our data show, however, that isolated occurrences of oil shale grade lithologies (i.e. rocks that yield more than 25 l/t) are known north of Debert and near McCallum Settlement. It is unknown whether these occurrences are laterally continuous and estimates of potential resources await further understanding of the basin's stratigraphy and structural complexity.

References Cited: Debert-Kemptown Basin

Bell, W. A., 1958.

Calder, J. H., 1985b.

Calder, J. H. and Naylor, R. D., 1989.

Clapp, F. G., 1915.

Donohoe, H. V. and Wallace, P. I., 1982d.

Drummond, R., 1918.

Ells, R. W., 1909, 1910.

Flynn, A. E., Grant, R. I. and Murphy, G. F., 1940.

Gunn, J., Molyneaux, P. and Fraser, E., 1987.

Lortie, D. P., 1979.

Naylor, R. D., 1988.

Naylor, R. and Molyneaux, P., 1988.

Potter, W., 1977.

Smith, E., 1975.

Smith, E. W. and Gillis, K. S., 1978.

Stevenson, I. M., 1958.

Wright, J. D., 1975.

Additional Selected References: Debert-Kemptown Basin

Bisson, L. M., Gregory, D. J. and Richardson, J. M., 1978.

Covert, T. G. N., 1975a, 1975b.

Fletcher, H., 1891.

Gillis, K. S., Smith, E. W. and Covert, T. G. N., 1976.

Hacquebard, P. A. and Donaldson, J. R., 1970.

Robbins, B., 1969.

Shea, F. S., 1977.

Smith, E. W., Gillis, K. S. and Covert, T. G. N., 1977.

LATE PENNSYLVANIAN TO PERMIAN (LATE WESTPHALIAN B/C-STEPHANIAN)

The following section includes those areas of the Province containing Late Pennsylvanian (locally to Permian) strata that have been reported to contain oil shale. Strata of this age have been assigned to the coal-bearing equivalents of the Pictou Group and occur within the Mabou-Inverness coalfield, Stellarton Basin, Sydney Basin and Trenton Syncline.

Mabou - Inverness Coalfield

Stratigraphy, Age and Depositional Environment

The Mabou-Inverness coalfield (Fig. 12) was first regarded as a potential oil shale site by Robbins (1969; Table 1). Kalkreuth and Gibling (1987b) first sampled and tested oil shale lithologies (black shale) from this area and Gibling and Kalkreuth (in press) first described them. Strata within the coalfield are assigned to the coal-bearing Inverness Formation (Pictou Group), of Westphalian C to Stephanian age (Hacquebard and Donaldson, 1969; Hacquebard, 1980, 1986; Hacquebard *et al.*, 1989; Gibling, 1985a). The formation comprises grey and buff arkosic sandstone, conglomerate, red and grey shale, black shale and coal deposited in a fluvial-deltaic and associated swamp setting (Norman, 1935; Hacquebard and Donaldson, 1969; Gibling, 1985a). In the Lake Ainslie area the formation is 950 m thick (Bell, 1958) and on Henry and Hood Islands it is over 600 m thick (Norman, 1935). The basal 360 m of the formation, exposed in coastal section at Mabou, contain seven major coal seams and the upper 540 m of the formation, exposed in coastal section at Inverness, contain four major coal seams (Hacquebard *et al.*, 1989). The coal was mined periodically at Mabou (1899-1909) and Inverness (1865-1960s) (Calder *et al.*, 1985). Hacquebard *et al.* (1989) have used the results of offshore drilling (holes M-1 and M-2A: Fig. 12) and seismic surveys to demonstrate that the Mabou and Inverness sections are continuous in offshore areas. The strata occur within the Gulf of St. Lawrence Coal Basin (Hacquebard, 1986) which covers an area of 46 620 km^2. This large area includes the region occupied by much of the Gulf of St. Lawrence and the onland Pennsylvanian strata of New Brunswick.

Late Westphalian C to Westphalian D palynomorphs recovered from the Inverness Formation show that the formation is age equivalent to parts of the Morien Group (Hacquebard and Donaldson, 1969; Hacquebard, 1986; Hacquebard *et al.*, 1989; Gibling, 1985a). In fact, Hacquebard *et al.* (1989) have correlated the laterally extensive 7 Foot seam, of the upper part of the formation (Inverness Section), with the Harbour seam of the Sydney Mines Formation. The possible continuity of the Harbour seam into the Gulf of St. Lawrence Coal Basin as the 7 Foot seam suggests that contemporaneous coal deposition occurred for an unknown period of time throughout a vast area occupied by what are now the Sydney and Gulf of St. Lawrence coal basins (Hacquebard *et al.*, 1989).

Oil Shale

Robbins (1969) first considered the Inverness Formation as potentially containing "pyrobituminous shale" (oil shale). Such shale occurs within the basal 200-250 m of the Inverness Formation (below the 7 Foot seam: Mabou Mines Section) and includes cannel shale (from a 0.35 m thick bed directly underlying the 7 Foot seam and which grades into 3.0 m of fissile shale), fissile shale (0.40 m thick beds), and resistant, blocky, petroliferous shale (0.50 m thick beds). The fissile shale and petroliferous shale beds contain pelecypods fossils.

Samples of cannel shale, fissile shale and petroliferous shale from the basal part of the formation, exposed in coastal section at Mabou Mines (Fig. 12), were obtained for analysis of oil yield, organic content, mineralogy and combustion performance (the results are presented in Appendix 1.9). The analyses show the lithologies to be rich in organic carbon (contents of 6.1 - 13.7%) and give yields of 8.8-40.8 l/t; cannel shale gave the highest yield. The organic matter contained in these rocks is near the onset of thermal maturation (TMAX = 427 - 432°C) and the hydrogen indices (HI = 181 - 389) are consistent with organic matter comprising mainly humic/terrestrial material (vitrinites, inertinites) with a minor contribution of exinites. X-ray diffraction) analyses show all shale types to be silicate-rich (silicates constitute 94% of the inorganic component). Combustion testing of the fissile shale gave 1678 BTU/lb. with ash contents of about 80%.

Comparable results to these were obtained by Kalkreuth and Gibling (1987b), who sampled three

Figure 12. Geology of the onshore part of the Mabou-Inverness coalfield (after Norman, 1933; Potter, 1978; Hacquebard et al., 1978, 1989) showing the location of drillholes and outcrop samples taken for testing. See Appendix 1.9a-d for results of the analyses.

black shale beds, also from the Mabou Mines section. Their results indicated organic carbon contents of 2.5-13% and hydrocarbon yields of 2.5-38 l/t. Using organic petrography, they reported an organic component rich in vitrinite for two of the samples and a spore-rich organic component for the third sample.

The data collected for this project, and those of Kalkreuth and Gibling (1987b), confirm the presence of oil shale grade lithologies within the Mabou Mines section of the Inverness Formation. In particular, a 0.35 m thick bed of cannel shale underlying the 7 Foot seam offers the greatest hydrocarbon yield of the beds tested. However, resources are situated offshore and structural interpretations by Hacquebard *et al.* (1989) indicate that the seam and its underlying cannel shale are too deep in nearshore areas to provide significant tonnages for mining.

References Cited: Mabou - Inverness Coalfield

Bell, W. A., 1958.

Calder, J. H., Bain, C. E., Chesal, S., Gillis, K., MacNeil, D. J., Naylor, R. D. and Palmer, W. J., 1985.

Gibling, M., 1985a.

Gibling, M. R. and Kalkreuth, W. D., in press.

Hacquebard, P. A., 1980, 1986.

Hacquebard, P. A., Cameron, A. R., Forgeron, S. V., Potter, W. C., Shaw, W. S. and Smith, E. W., 1978.

Hacquebard, P. A. and Donaldson, J. R., 1969.

Hacquebard, P. A., Gillis, K. S. and Bromley, D. A., 1989.

Kalkreuth, W. and Gibling, M. R., 1987b.

Norman, G. W. H., 1933, 1935.

Potter, W., 1978.

Robbins, B., 1969.

Additional Selected References: Mabou-Inverness Coalfield

Cameron, H. L., 1948.

Deal, A. J., 1986.

Dickie, J. R., 1986.

Gregory, D. J., 1978.

Stellarton Basin

Stratigraphy, Age and Depositional Environment

Oil shale was first discovered in the Stellarton Basin of northern Nova Scotia in the 1850s (How, 1868; Table 1). The basin occupies an area of approximately 165 km^2 (Fig. 13) and is situated in a structurally complex area between the Cobequid Highlands Massif and Antigonish Highlands Massif (Naylor and Smith, 1986b) (Fig. 1). Major and minor faults related to the Cobequid-Chedabucto Fault System extend near or through the basin and are believed to have been important in basin formation as well as being limiting factors in resource exploration and development (Naylor and Smith, 1986b). Fralick and Schenk (1981) suggested that the Stellarton Basin developed as a pull-apart basin in response to termination of a major dextral strike-slip fault (the Hollow Fault) during Westphalian time. Recent field observations along the fault systems within and bounding the basin suggest that it formed as a rhomb-graben in response to Westphalian B-C dextral strike-slip movement along the Hollow and Cobequid Fault Systems (Yeo and Ruixiang, 1986).

Strata exposed within the basin comprise a 2600 m thick grey and red sequence of sandstone, shale and conglomerate with substantial coal and oil shale (Bell, 1940; Hacquebard and Donaldson, 1969). The succession represents deposition in a complex lacustrine and alluvial-fluvial setting (Hacquebard and Donaldson, 1969) characterized by rapid lateral facies changes (Naylor and Smith, 1986b). The sequence was named the Stellarton Series by Bell (1926, 1940) and subsequently assigned group status (Bell, 1944). Recent workers (Fralick and Schenk, 1981; Yeo and Ruixiang, 1986; Yeo, 1987b; Naylor *et al.*, 1989), however, have followed Fralick's (1980) usage, referring to

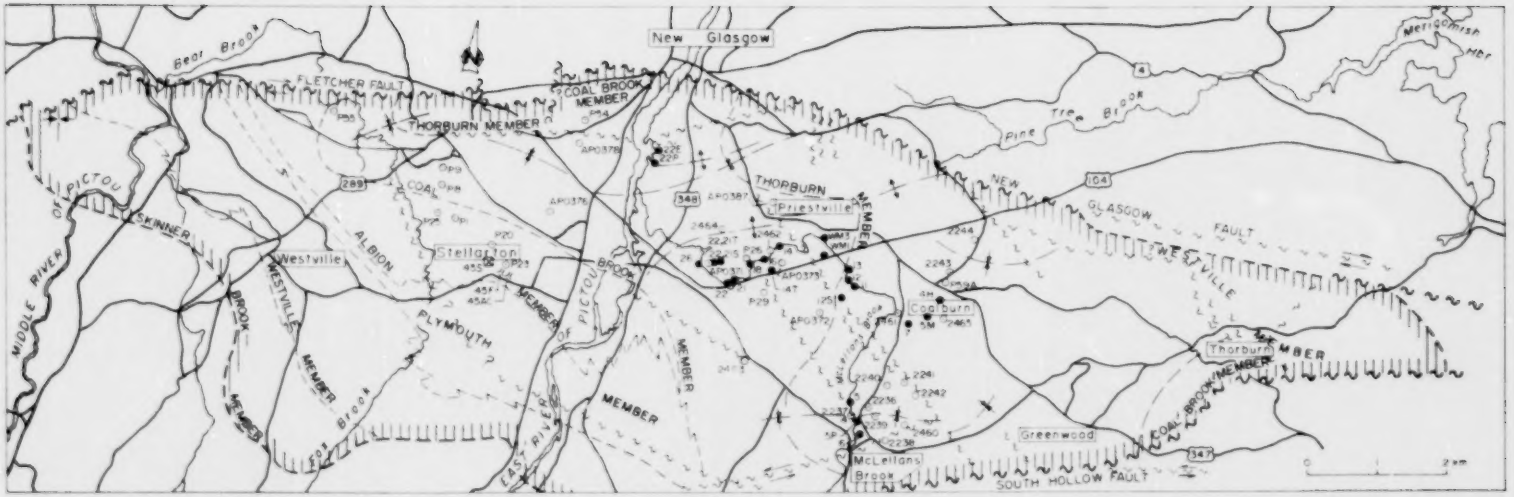

Figure 13. Geology of the Stellarton Basin (Pictou coalfield) (after Bell, 1940; Gillis, 1985; Yeo, 1987a, 1987b; Yeo and Ruixiang, 1986, 1987; Naylor et al., 1988a; Smith et al., 1989a; Naylor et al., 1989) showing the location of drillholes, outcrops and mines from which samples were obtained for analyses. This map shows only the geology within the basin and the location of those drillholes from which oil shale samples were taken for analyses. See the maps of Naylor et al. (1988a) and Smith et al. (1989a) for the geology outside of the basin boundaries (unpatterned area) and for the location of all drillholes within the basin. Sample locations include:

4H	-	Oil Shale 4, Haliburton's Pit
4	-	Oil Shale 4 outcrop, McLellan's Brook
5M	-	Oil Shale 5 outcrop, Marsh Brook
5P	-	Oil Shale 5, Patrick Slope
5	-	Oil Shale 5 outcrop, McLellan's Brook, 210 m NW of Patrick Slope
6	-	Oil Shale 6 outcrop, McLellan's Brook
7	-	Oil Shale 7/Sixfoot seam outcrop, Marsh Brook
11	-	Oil Shale 11 outcrop, junction of Shale and McLellan's Brooks
12	-	Oil Shale 12 outcrop, McLellan's Brook
12S	-	Oil Shale 12 outcrop, Shale Brook
13	-	Oil Shale 13/McBean seam outcrop, McLellan's Brook
WM1	-	Widow McLean 1st horizon, Roadcut, Trans-Canada Highway
WM3	-	Widow McLean 3rd horizon outcrop, McLellan's Brook
14	-	Oil Shale 14 outcrop, McLellan's Brook
14T	-	Oil Shale 14 outcrop, McLellan's Brook tributary
16	-	Oil Shale 16 outcrop, McLellan's Brook
18	-	Oil Shale 18 outcrop, McLellan's Brook
21	-	Oil Shale 21 outcrop, McLellan's Brook
21S	-	Oil Shale 21, Shaw Pit
21T	-	Oil Shale 21, section at Torbanite Products Ltd. slope
22	-	Oil Shale 22 outcrop, McLellan's Brook
22S	-	Oil Shale 22, Shaw Pit
22T	-	Oil Shale 22, section at Torbanite Products Ltd. slope
22P	-	Oil Shale 22 outcrop, near Potter's Brook
22E	-	Oil Shale 22 outcrop, East River
26	-	Oil Shale 26 outcrop, McLellan's Brook
45AC	-	Oil Shale 45, Acadia Coal Co. Mine, Coal Brook
45F	-	Oil Shale 45, Frazier Mine
45S	-	Oil Shale 45, Stellar Pit

See Appendix 1.10a-g for identification of the samples taken at each drillhole, outcrop, pit or mine location and for the results of the analyses.

the strata as the Stellarton Formation.

Bell (1940) subdivided the sequence into two divisions with three members each (Fig. 14). The lower division (Division I) consists of a grey coal-bearing member (Westville) between two redbed members, the Plymouth above and Skinner Brook below. Contacts between the members are gradational and diachronous. The upper division (Division II) consists of the intermediate Coal Brook Member of oil shale and claystone lying between the coal- and oil shale-bearing Thorburn Member above, and the Albion Member below.

Recent diamond-drilling in the basin by Brinco (Brinco Mining Limited, 1982), Suncor (Fraser, 1986), Placer (Bielenstein *et al.*, 1987) and NSDME (1974-1987), and detailed surface mapping of the basin by NSDME (Naylor *et al.*, 1985, 1986a, 1986b, 1987a, 1987b, 1987c, 1988a, 1988b, 1988c, 1989; Naylor and Smith, 1986a, 1986b, 1988b; Smith *et al.*, 1988, 1989a, 1989b) and Geological Survey of Canada (Yeo, 1987a, 1987b; Yeo and Ruixiang, 1986, 1987; Snow, 1988) have added to the available stratigraphic information. In particular, refinements to the stratigraphy of the formation since Bell's (1940) subdivision include: (1) recognition of 60 oil shale beds and 35 coal seams within the formation, (2) recognition that strata assigned to the Coal Brook Member in basin margin areas are mainly coarse grained lithologies, including sandstone and siltstone with minor conglomerate, interbedded with coaly shale, thin banded coal, carbonaceous shale and minor oil shale and claystone sequences, and (3) recognition that the Plymouth Member interfingers with the upper part of the Westville Member, with the Albion Member, and with the Coal Brook Member to the level of the McLeod seam.

On the basis of macroflora and macrofauna, Bell (1940) assigned a Westphalian B-C age to the lower part of the Stellarton Formation. Lack of diagnostic fossils prevented an age assignment for the upper part. Based on the palynology of major coal seams, Hacquebard and Donaldson (1969) reported a Westphalian B-C age for the entire Stellarton Formation. Further palynological studies of Stellarton Formation coal and mudstone by Dolby (1986a, 1986b) indicate that the upper part of the Stellarton Formation is as young as early Westphalian D (Naylor *et al.*, 1987c). The age interpretation of the strata has been refined by recent palynological studies (Yeo *et al.*, 1988a) which indicate a probable Westphalian B age for the lower part of the Skinner Brook Member, an early Westphalian C age for the Westville Member, a late Westphalian C age for the Albion Member, and an early Westphalian D age for the Thorburn Member.

Despite its small size, the Stellarton Basin has been an important producer of coal for many years (1825 - present; Calder *et al.*, 1985). Opportunities still exist for further development and exploration including: development of the Foord (east of former workings), Acadia and McLeod coal seams and the possibility of undiscovered coal within the Coal Brook, Albion and Westville Members (Naylor *et al.*, 1986b, 1987b; Smith *et al.*, 1988, 1989a).

Oil Shale

The Stellarton Formation contains Nova Scotia's best known and largest oil shale resource. The earliest description of the Stellarton oil shale was by How (1868). This oil shale resource has been the focus of interest as a potential source of hydrocarbons since then (Douglas and Campbell, 1942) and limited-scale mining occurred during two periods, 1852-1859 and 1929-1930 (Ells, 1910; Swinnerton, 1930; Douglas and Campbell, 1942).

Sixty oil shale beds have been documented in the Stellarton Formation (Smith *et al.*, 1988; 1989a, 1989b, 1989c; Naylor *et al.*, 1989); these are assigned numbers 1 to 60 from youngest to oldest (Fig. 14). Oil shale beds 1-13 are contained within the Thorburn Member, 14-42 within the Coal Brook Member, 43-54 within the Albion Member and 55-60 within the Westville Member (Fig. 14). Individual oil shale beds are separated by sandstone, siltstone, claystone and/or coal. Earlier workers including How (1868), Ells (1909), Flynn (1926), Swinnerton (1930), Macauley and Ball (1984) and Macauley *et al.* (1985) recognized that some of the formation's 35 coal seams are vertically and laterally transitional to oil shale. We have recognized that oil shale beds 7, 13, 33b, 44, 46, 49, 52 and 58 directly overlie coal seams and oil shale beds 45, 47, 48, 50 and 55 directly underlie coal seams. For further details on this association of coal and oil shale, the reader is directed to Naylor *et al.* (1986b), Kalkreuth and Macauley (1987), Paul (1988), Paul *et al.* (1988, 1989), von Ulrich (1988), Smith *et al.* (1989c) and Puttmann and Kalkreuth (1989).

The average thickness of each oil shale bed is 5.1 m, but they vary laterally. The thickest oil shale bed within the formation is oil shale 14, which attains a maximum thickness of 35.32 m in drillhole AP0397. In contrast, the thinnest oil shale bed is oil shale 11 of which only 0.29 m was cored

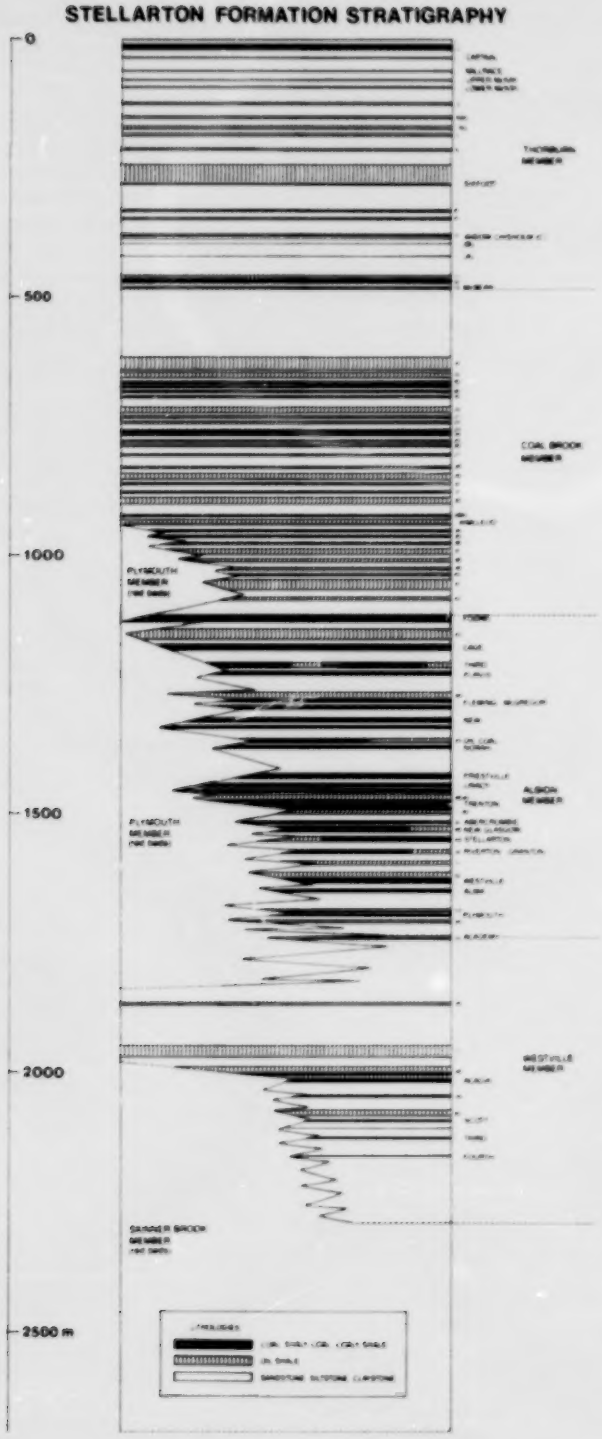

Figure 14. Detailed stratigraphy of the 2600 m thick Stellarton Formation (after Naylor and Smith, 1986a, 1986b; Smith et al., 1988, 1989a, 1989b) showing the stratigraphic position of the 60 (numbered) oil shale beds and 35 (named) coal seams. Member boundaries modified from Bell (1940).

in drillhole NS2238. Individual oil shale beds are laterally continuous over 3-5 km (Naylor *et al.*, 1985) in central basin areas, except where disrupted by faulting. The most extensive and thickest development of oil shale occurs within strata of the Coal Brook Member. In central basin areas, this member is about 500 m thick with oil shale constituting 45% of the section; the Coal Brook Member underlies an area of approximately 27.5 km^2 (Fig. 13).

The hydrocarbon yield, organic content, combustion performance, mineralogy and inorganic geochemistry of the oil shale beds have been extensively analyzed by various workers including Ells (1909), Bell (1924), Flynn (1926), Swinnerton (1930), Douglas and Campbell (1942), Goudge (1957a, 1957b), Potter (1974, 1976b), Chevron (1986), Macauley and Ball (1984), Rockwell and Munroe (1984), Hutton (1986), Naylor and Smith (1986b), Kalkreuth and Macauley (1986, 1987), Paul (1988), von Ulrich (1988) and Puttmann and Kalkreuth (1989). The results of these tests are presented in Appendices 1.10a-1.10g and are summarized in Table 5.

All of the oil shale samples tested have a silicate-rich mineral component comprising a groundmass of clays (dominated by illite with trace kaolinite and chlorite), with quartz and minor carbonate (mainly siderite). Average hydrocarbon yields of 1-88 l/t have been obtained for those oil shale beds tested. Of the 60 oil shale beds, 50% have maximum yields in excess of 25 l/t, the remainder have maximum yields of less than 25 litres per tonne and are best referred to as organic-rich shale, or have not been tested for their hydrocarbon yield (e.g. oil shale beds 46-60). The highest hydrocarbon yields (greater than 100 l/t) have been obtained from oil shale beds 4a, 4, 5, 21, 22 and 45. Maximum yields of 250 l/t were obtained from oil shale bed 5 and yields of 233-629 l/t were reported from six selected samples of oil shale bed 45 by Ells (1909), Flynn (1926) and Swinnerton (1930); these high yields have not been repeated in subsequent investigations in which average yields of 62 l/t have been obtained (based on 36 analyses).

Three lithologies form the Stellarton oil shale beds: fissile shale, cannel (massive) shale and boghead shale (stellarite) (Naylor *et al.*, 1987b; Yeo *et al.*, 1988b; Kalkreuth *et al.*, 1988). Fissile shale is the most common and it constitutes a portion of virtually every oil shale bed. Cannel shale, likewise, forms part of most oil shale beds (especially oil shale beds 4, 7, 12-16, 19-23, 26-28, 33b, 42, 44, 46-50, 52 and 58) but it accounts for only thin sections (≤30 cm) and a small proportion of the oil shale bed overall. Boghead shale is known to occur in oil shale beds 4a, 4-6, 45, 55 and 56 where it forms 0.15-1.85 m thick beds.

The fissile shale beds weather easily and split readily along bedding planes. They typically have a low organic content (average 5 wt. %) comprising algal debris with minor humics, and give hydrocarbon yields of generally less than 25 l/t of rock. The cannel shale is massive, resistant to fracture, and breaks with a conchoidal fracture. Cannel shale beds are transitional to coal, contain up to 40 wt. % organic carbon rich in amorphous liptinites with minor telalginite and vitrinite, and give hydrocarbon yields of 7-130 l/t (40 l/t, average) of rock. Combustion testing of cannel shale from oil shale bed 22 gave a value of 7800 BTU/lb., which is comparable to some Western Canadian coals currently in production. The boghead shale contains small (millimetre scale), ellipsoidal, amber-coloured grains that are concentrated locally in thin bands that fluoresce and give the rock a banded appearance when exposed to long wavelength ultra-violet light. Boghead shale samples have an average organic carbon content of 19 wt. % which comprises mostly algal remains (telalginite). Average hydrocarbon yields are 110 l/t of rock. Combustion testing of boghead shale from oil shale beds 4, 5, 6 and 45 gave values of 150-4500 BTU/lb. Testing of the pyrolysis liquids derived from the richest oil shale lithologies, cannel shale (from oil shale beds 13, 14, 21 and 22) and boghead shale (from oil shale bed 45), by Swinnerton (1930), Potter (1974) and Naylor and Smith (1986b) indicates that about half (43-65%) of the liquid products are mid-distillates (includes kerosene and diesel). The remaining products consist of napthas (includes naptha and gasoline; 7.5-25%) and residuum (20-47%).

The total oil shale resource is estimated to be 825 x 10^6 tonnes with 168 x 10^6 barrels of shale oil *in situ* (Table 5). This figure includes tonnages from oil shale beds with maximum yields in excess of 25 l/t and therefore only represents 48% of the total number of oil shale beds. The resources available from the four richest beds (4, 5, 22 and 45) total 40.6 x 10^6 tonnes with 17.18 x 10^6 barrels of shale oil *in situ*; the beds are about 3.0 m thick with about 565 m of coal- and oil shale-bearing strata separating oil shale beds 5 and 22, and 22 and 45. Previous estimates of the available resources of this area were given as 500 x 10^6 tonnes by Spence (1918). Rockwell and Munroe (1984) reported that in excess of 1.0 x 10^6 tonnes of stockpiled oil shale (from oil shale bed 22) are available at the onsite dump areas of the L. E.

Table 5. *Summary of laboratory test results and estimates of oil shale resources, to a depth of 400 m, for oil shale beds 1-46a, Stellarton Basin. n = number of analyses; T.O.C. = total organic carbon; Ro = vitrinite reflectance; m.m.f. = mineral matter free; bbls = barrels; EX = exinites; VIT = vitrinites; IN = inertinites; WFG = weakly fluorescing groundmass; QU = quartz; FS = feldspar; PY = pyrite; OTH = other minerals; GYP = gypsum; AP = apatite; RH = rhodochrosite.*

		OIL SHALE NO.						OIL SHALE NO.			
ANALYSIS		1	2	3	4a	4	5	6	7	8	9
Oil Yield (l/t)	Range	55.9-79.8	22.0	55.9	49.9-175.2	6.0-145.7	6.0-249.5	4.3-68.9	2.9-63.9	16.0-65.9	22.0-27.9
	Average	67.9	22.0	55.9	87.8	74.5	85.9	22.6	24.5	31.2	25.9
	n	2	1	2	12	26	55	26	67	14	5
	Anomalies							144.7, 264.5	35.9, 47.8		
T.O.C. (wt %)	Range	-	-	-	-	14.5	16.5-28.2	-	2.2-15.6	-	-
	n	-	-	-	-	1	4	-	5	-	-
	Anomalies										
Hydrogen Index (H.I.)	Range	-	-	-	-	591	859-957	-	136-347	-	-
	n	-	-	-	-	1	4	-	5	-	-
	Anomalies										
Ro (Mean)	Range	-	-	-	-	-	-	-	0.70	-	0.41
	n	-	-	-	-	-	-	-	1	-	1
Petrography (Range; % m.m.f.)	EX	-	-	-	-	57	98	-	12-27	-	8
	VIT	-	-	-	-	1	1	-	0-27	-	tr
	IN	-	-	-	-	2	1	-	4-14	-	2
	WFG	-	-	-	-	60	0	-	44-84	-	90
	n	-	-	-	-	1	1	-	1	-	1
Inorganic Geochem (%)	Fe	-	-	-	-	-	-	-	-	-	-
	Al	-	-	-	-	-	-	-	-	-	-
	Si	-	-	-	-	-	-	-	-	-	-
	Ca,Mg	-	-	-	-	-	-	-	2	-	-
	n	-	-	-	-	-	-	-	1	-	-
Mineralogy (Range and mean; in %)	Clays	-	-	-	-	-	65-77	-	-	-	-
	QU, FS	-	-	-	-	-	13-16	-	-	-	-
	Carbonates	-	-	-	-	-	4-19	-	-	-	-
	PY	-	-	-	-	-	5	-	-	-	-
	OTH	-	-	-	-	-	0	-	-	-	-
	n	-	-	-	-	-	2	-	-	-	-
Specific Gravity	Range	-	-	-	-	1.68-2.22	1.747-2.43	1.63-1.91	2.29	-	-
	Average	2.58**	2.58**	2.58**	2.58**	1.97	1.96	1.79	2.29	2.58**	2.58**
	n	-	-	-	-	4	5	2	1	-	-
Combustion Testing	Moisture %	-	-	-	-	1.02	0.62-1.1	0.2-0.7	-	-	-
	Volatiles %	-	-	-	-	27.44	22.5-33.91	21.4-31.8	-	-	-
	Ash %	-	-	-	-	62.28	59.88-62.6	66.8-71.7	-	-	-
	Carbon %	-	-	-	-	9.26	0.0-6.11	6.2-7.2	-	-	-
	Sulphur %	-	-	-	-	0.65	0.48	0.35-0.51	-	-	-
	BTU/LB	-	-	-	-	2260	2260-4511	151-1430	-	-	-
Available Resources	Tonnes	319,848 t	-	854,122.5 t	8.87×10^6 t	8×10^6 t	13.65×10^6 t	5.95×10^6 t	46.35×10^6 t	10.5×10^6 t	8.75×10^6 t
	Shale Oil In Situ	129,495 bbls	-	214,590 bbls	5.4×10^6 bbls	5.5×10^6 bbls	6.9×10^6 bbls	0.9×10^6 bbls	7.9×10^6 bbls	2.3×10^6 bbls	1.59×10^6 bbls
	Avg. Thickness	1.78m	1.51m	0.87m	2.68m	2.62m	3.60m	2.39m	14.56m	4.92m	6.09m

**Source of mineralogy data is Macauley and Ball (1984). The mineral percentages reported represent relative peak heights obtained from X-ray diffraction diffractograms and are not absolute values. Semi-quantitative values for the minerals present can be obtained by multiplying Macauley and Ball's (1984) values by the intensity factor of the mineral (from Umpleby et al., 1978; Cook et al., 1975; and Piper, 1977). Application of intensity factors to the determination of mineral abundance is required in order to correct for differences in the diffraction ability of various minerals caused by differences in mass absorption. The intensity factors are calculated relative to the primary quartz peak which is assigned an intensity factor of 1.00. Intensity factors for commonly occurring minerals are: quartz = 1.00; illite = 4.00; montmorillonite/smectite = 1.00; kaolinite/chlorite = 2.00; albite = 2.80; K-feldspar = 4.30; calcite = 1.65; dolomite = 1.53; siderite = 1.15; and pyrite = 2.30.*

***No data on specific gravity; specific gravity is the average value calculated from 126 measurements obtained from other oil shale beds.*

- indicates not determined; tonnage estimates not calculated for oil shale beds due to lack of sufficient data or maximum yields of less than 25 l/t.

Table 5. (continued)

ANALYSIS		OIL SHALE NO. 10	11	12	13	WIDOW MEL 1st	WIDOW MEL 3rd	OIL SHALE NO. 14	15	16	17
Oil Yield (l/t)	Range	8.0-29.9	20.0-87.8	11.5-69.9	14.0-51.9	88.0	41.4	27.9-55.9	12.0-33.9	22.0-38.9	20.0-30.0
	Average	20.0	53.9	42.2	30.3	88.0	41.4	43.0	22.5	31.5	25.3
	n	3	2	5	13	1	1	11	4	11	6
	Anomalies										
T.O.C. (wt %)	Range	-	-	-	7.6-15.9	7.1	-	14.2	-	7.8	-
	n	-	-	-	6	1	-	1	-	1	-
	Anomalies										
Hydrogen Index (H.I.)	Range	-	-	-	252-428	422	-	490	-	566	-
	n	-	-	-	6	1	-	1	-	1	-
	Anomalies										
Ro (Mean)	Range	-	-	-	-	-	-	-	-	-	-
	n	-	-	-	-	-	-	-	-	-	-
Petrography (Range; % m.m.f.)	EX	-	-	-	5-12	12	11	-	-	-	-
	VIT	-	-	-	1-47	1	5	-	-	-	-
	I%	-	-	-	5-92	3	2	-	-	-	-
	MFG	-	-	-	40-91	84	62	-	-	-	-
	n	-	-	-	3	1	1	-	-	-	-
Inorganic Geochem (%)	Fe	-	-	-	-	-	-	-	-	-	-
	Al	-	-	-	-	-	-	-	-	-	-
	Si	-	-	-	-	-	-	-	-	-	-
	Ca,Mg	-	-	-	-	-	-	-	-	-	-
	n	-	-	-	-	-	-	-	-	-	-
Mineralogy (Range and mean; in %)	Clays	-	-	-	28-46*	-	-	-	-	33*	-
	QR, FS	-	-	-	52-68*	-	-	-	-	51*	-
	Carbonates	-	-	-	1-2*	-	-	-	-	7*	-
	PY	-	-	-	0-1*	-	-	-	-	3*	-
	OTH	-	-	-	0-2(GYP)*	-	-	-	-	0-4(GYP,APT)*	-
	n	-	-	-	3	-	-	-	-	1	-
Specific Gravity	Range	-	-	-	2.285	2.205	-	-	-	-	-
	Average	2.58**	2.58**	2.58**	2.285	2.205	2.58**	2.58**	2.58**	2.58**	2.58**
	n	-	-	-	1	1	-	-	-	-	-
Combustion Testing	Moisture %	-	-	1.4-2.1	1.4-2.2	-	0.8	-	-	2.6-3.6	-
	Volatiles %	-	-	11.1-14.2	10.7-14.1	-	15.4	-	-	13.2-13.9	-
	Ash %	-	-	82.8-87.7	82.8-86.2	-	79.4	-	-	80.4-80.6	-
	Carbon %	-	-	0.0-2.1	0.9-1.7	-	4.4	-	-	2.0-3.6	-
	Sulphur %	-	-	-	-	-	-	-	-	-	-
	BTU/LB	-	-	-	-	-	-	-	-	-	-
Available Resources	Tonnes	16.9×10^6 t	6.0×10^6 t	10.8×10^6 t	2.27×10^9 t	-	-	127.9×10^6 t	43.85×10^6 t	23.3×10^6 t	20.3×10^6 t
	Shale Oil In Situ	2.9×10^6 bbls	2.25×10^6 bbls	9.2×10^6 bbls	5.7×10^8 bbls	-	-	38.5×10^6 bbls	6.9×10^6 bbls	5.1×10^6 bbls	5.6×10^6 bbls
	Avg. Thickness	6.45m	1.33m	2.99m	3.76m	-	-	22.63m	7.19m	3.56m	3.13m

Shaw Brick Company clay pit site.

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***Table 5.** (continued)*

ANALYSIS		OIL SHALE NO. 18	19	20	21	22	23	24	25	26	27
Oil Yield (l/t)	Range	22.0-55.4	14.0-37.9	1.4-53.9	9.8-139.7	tr-152.2	3.2-69.9	3.7-26.0	5.6-22.0	20.0-68.7	15.4-31.9
	Average	37.7	25.6	25.7	38.5	31.4	21.4	13.1	12.2	39.6	22.8
	n	5	5	30	31	138	18	23	7	6	4
	Anomalies				1.0						
T.O.C. (wt %)	Range	-	-	1.0-9.8	3.5-35.6	0.3-43.5	1.7-8.2	2.1-8.2	3.1-5.4	22.1	5.5
	n	-	-	12	10	116	12	10	3	1	1
	Anomalies				1.0						
Hydrogen Index (H.I.)	Range	-	-	146-443	225-445	182-496	195-575	103-617	178-309	314	291
	n	-	-	12	10	102	12	10	3	1	1
	Anomalies				91	5<100;97>640					
Ro (Mean)	Range	-	-	0.60-0.76	0.43-0.59	0.41-0.71	-	-	-	-	-
	n	-	-	2	3	11	-	-	-	-	-
Petrography (Range; % o.e.f.)	EX	-	-	2-6	tr-36	0-46	-	-	-	-	-
	Vit	-	-	0-tr	0-61	0-79	-	-	-	-	-
	In	-	-	tr-1	tr-9	tr-15	-	-	-	-	-
	MFG	-	-	93-97	58-99 (one sample MFG = 16%)	0-99	-	-	-	-	-
	n	-	-	2	7	25	-	-	-	-	-
Inorganic Geochem (%)	Fe	-	-	6.0	6.2	5.3-9.7	-	-	-	-	-
	Al	-	-	20.7	19.1	11.4-21.2	-	-	-	-	-
	Si	-	-	65.1	67.2	39.0-64.8	-	-	-	-	-
	Ca,Mg	-	-	3.2	2.8	1.9-3.7	-	-	-	-	-
	n	-	-	1	1	6	-	-	-	-	-
Mineralogy (Range and mean; in %)	Clays	-	-	30-58*	32-47*	56-65	41-50*	-	-	38*	47*
	QU, FS	-	-	39-65*	48-66*	28-34	41-51*	-	-	55*	50*
	Carbonates	-	-	0-19*	1-5*	6-8	4-9*	-	-	2*	1*
	Py	-	-	0-3*	0-2*	0-3	0-1*	-	-	5*	2*
	Oth	-	-	0-4(AP?)*	0-3(KHT,AP?)*	0	0*	-	-	0*	0*
	n	-	-	12	8	3	3	-	-	1	1
Specific Gravity	Range	-	-	2.43	1.86-2.38	1.16-3.16	2.495-2.86	2.47-2.775	2.565-2.64	2.15	-
	Average	2.38**	2.38**	2.43	2.07	2.28	2.61	2.60	2.61	2.15	2.36*
	n	-	-	1	3	32	9	18	3	1	-
Combustion testing	Moisture %	2.3-3.0	-	-	1.1	0.067-1.9	-	-	-	-	-
	Volatiles %	17.5-17.7	-	-	26.4	16.5-30.07	-	-	-	-	-
	Ash %	76.9-79.2	-	-	51.0	47.5-75.4	-	-	-	-	-
	Carbon %	0.7-2.6	-	-	19.5	6.2-25.9	-	-	-	-	-
	Sulphur %	-	-	-	-	-	-	-	-	-	-
	BTU/LB	-	-	-	-	7843	-	-	-	-	-
Available Resources	Tonnes	15.9x10^6 t	19.3x10^6 t	56.95x10^6 t	30.6x10^6 t	15x10^6 t	32.15x10^6 t	35.9x10^6 t	-	24.9x10^6 t	25.5x10^6 t
	Shale Oil In Situ	4.2x10^6 bbls	3.45x10^6 bbls	10.2x10^6 bbls	8.25x10^6 bbls	5.1x10^6 bbls	4.8x10^6 bbls	5.3x10^6 bbls	-	6.2x10^6 bbls	4.07x10^6 bbls
	Avg. Thickness	2.47m	2.85m	7.58m	4.76m	2.22m	3.93m	4.29m	2.83m	3.32m	3.03m

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Table 5. (continued)

ANALYSIS		OIL SHALE NO. 28	29	30	31	32	33a	33b	34	35	36
Oil Yield (l/t)	Range	12.5-37.9	13.6-30.7	14.0-31.9	8.9-11.7	4.0-18.2	3.6-4.7	2.5-93.7	3.2-15.5	1.4-10.8	6.0-24.4
	Average	23.0	24.2	22.0	10.3	9.8	3.9	28.5	7.5	6.9	12.4
	n	5	5	5	2	11	2	78	9	8	7
	Anomalies										
T.O.C. (wt %)	Range	5.7	11.3	-	4.0	2.8-6.1	2.6-4.2	2.1-29.6	1.7-11.5	1.8-5.9	3.0-8.9
	n	1	1	-	1	4	2	75	9	8	7
	Anomalies										
Hydrogen Index (H.I.)	Range	351	271	-	290	260-342	140-170	106-642	129-310	130-252	192-350
	n	1	1	-	1	4	2	75	9	8	7
	Anomalies										
Ro (Mean)	Range	0.60	-	-	-	-	-	0.56-0.92	-	-	-
	n	1	-	-	-	-	-	19	-	-	-
Petrography (Range; % n.m.r.	Ex	4	-	-	-	-	-	0-54	2-8	9	-
	Vit	0	-	-	-	-	-	1-58 (2 at 75%,88%)	9-13	21	-
	I%	1	-	-	-	-	-	0-24	8-14	5	-
	WFG	95	-	-	-	-	-	25-94 (2 at 15,18%)	71-75	65	-
	n	1	-	-	-	-	-	67	2	1	-
Inorganic Geochem (%)	Fe	-	-	-	-	-	-	11.5	-	-	-
	Al	-	-	-	-	-	-	15.5	-	-	-
	Si	-	-	-	-	-	-	36	-	-	-
	Ca,Mg	-	-	-	-	-	-	1.9	-	-	-
	n	-	-	-	-	-	-	1	-	-	-
Mineralogy (Range and mean; in %)	Clays	5*	5*	-	9*	45-59*	-	33-44*	-	-	39*
	QU, FS	55*	94*	-	50*	37-49*	-	43-58*	-	-	57*
	Carbonates	4*	4*	-	6*	1-5*	-	9-20*	-	-	2*
	PY	2*	5*	-	2*	0-2*	-	tr-2*	-	-	4*
	OTH	2* (APT)	1*	-	5* (APT)	0-3* (APT,GYP)	-	0*	-	-	tr*
	n	1	1	-	1	4	-	3	-	-	1
Specific Gravity	Range	-	-	-	-	-	2.635-2.67	2.18-2.85	2.445-2.67	2.56-3.20	2.44-2.635
	Average	2.56**	2.58**	2.58**	2.58**	2.58**	2.65	2.51	2.63	2.72	2.53
	n	-	-	-	-	-	2	13	9	8	6
Combustion Testing	Moisture %	-	-	-	-	-	-	-	-	-	-
	Volatiles %	-	-	-	-	-	-	-	-	-	-
	Ash %	-	-	-	-	-	-	-	-	-	-
	Carbon %	-	-	-	-	-	-	-	-	-	-
	Sulphur %	-	-	-	-	-	-	-	-	-	-
	BTU/LB	-	-	-	-	-	-	-	-	-	-
Available Resources	Tonnes	20.1×10^6 t	104.4×10^6 t	14.1×10^6 t	-	-	-	48.66×10^6 t	-	-	-
	Shale Oil In Situ	5.2×10^6 bbls	17.7×10^6 bbls	2.18×10^6 bbls	-	-	-	9.7×10^6 bbls	-	-	-
	Avg. Thickness	2.44m	12.79m	1.86m	5.68m	12.02m	4.10m	6.17m	3.08m	2.12m	2.99m

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Table 5. *(continued)*

ANALYSIS		Oil Shale No. 37	38	39	40	41	42	43	45	45a
Oil Yield (l/t)	Range	0.0-3.9	0.0-4.4	10.3	0.1-8.2	0.0-7.8	5.4-8.6	0.2-2.8	0.2-139.7	-
	Average	0.8	2.2	10.3	4.4	5.9	6.7	0.9	61.6	-
	n	5	2	1	7	2	1	7	96	-
	Anomalies								2 (>62.5 l/t)	
T.O.C. (wt %)	Range	-	2.8	-	2.5-3.8	4.4	4.7	-	0.5-25.5	-
	n	-	1	-	2	1	1	-	25	-
	Anomalies									-
Hydrogen Index (H.I.)	Range	-	140	-	182-209	176	164	-	80-455	-
	n	-	1	-	2	1	1	-	25	-
	Anomalies									-
Ro (Mean)	Range	-	-	-	-	0.71	-	-	0.36-0.47	0.44-0.47
	n	-	-	-	-	1	-	-	11	2
Petrography (Range; % m.m.f.)	EX	-	-	-	-	1	-	-	0-52	1-5
	VIT	-	-	-	-	5	-	-	0-25	1-5
	IN	-	-	-	-	1	-	-	0-8	2-12
	mFG	-	-	-	-	45	-	-	42-99	82-94
	n	-	-	-	-	1	-	-	12	2
Inorganic Geochem (%)	Fe	-	-	-	-	-	-	-	6.7	-
	Al	-	-	-	-	-	-	-	27.5	-
	Si	-	-	-	-	-	-	-	60.2	-
	Ca,Mg	-	-	-	-	-	-	-	3.1	-
	n	-	-	-	-	-	-	-	1	-
Mineralogy (Range and mean; in %)	Clays	-	5**	-	42-43*	45*	44*	-	14-88*	-
	Qtz, FS	-	5**	-	55-56*	50*	44*	-	2-87*	-
	Carbonates	-	2*	-	4*	4*	2*	-	0-25	-
	FY	-	0*	-	0*	1*	1*	-	0-8	-
	Oth	-	0*	-	0*	0*	0*	-	0-5*	-
	n	-	1	-	2	1	1	-	22	-
Specific Gravity	Range	-	-	-	-	-	-	-	1.00-2.29	-
	Average	2.5***	2.5***	2.5***	2.5***	2.5***	2.5***	2.5***	1.67	2.5***
	n	-	-	-	-	-	-	-	7	-
Combustion Testing	Moisture %	-	-	-	-	-	-	-	0.20-5.40	-
	Volatiles %	-	-	-	-	-	-	-	25.5-69.30	-
	Ash %	-	-	-	-	-	-	-	6.40-73.60	-
	Carbon %	-	-	-	-	-	-	-	2.40-36.20	-
	Sulphur %	-	-	-	-	-	-	-	0.05-0.34	-
	BTU/LB	-	-	-	-	-	-	-	2137	-
Available Resources	Tonnes	-	-	-	-	-	-	-	5.4x10⁹ t	-
	Shale Oil In Situ	-	-	-	-	-	-	-	1.6x10⁹ bbls	-
	Avg. Thickness	7.50m	5.75m	5.35m	4.56m	10.86m	2.45m	5.46m	4.69m	4.45m

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Sydney Basin

Stratigraphy, Age and Depositional Environment

Accounts of oil shale within the Sydney Basin (Figs. 15, 16) were first made by Hartley (in Selwyn, 1871; Table 1). The Sydney Basin covers an area of approximately 36 260 km^2 but is mostly (98%) submerged beneath the Cabot Strait. The Pennsylvanian Morien Group constitutes approximately 50% of the 4 km thick basin-fill (Bell, 1938; Hacquebard, 1986; Rust *et al.*, 1987). The Morien Group, of fluvio-lacustrine (Hayes and Bell, 1923; Belt, 1968; Hacquebard and Donaldson, 1969; Vasey and Zodrow, 1983; Gibling, 1985b; Gibling and Rust, 1986, 1987; Forgeron *et al.*, 1982) and fresh to brackish coastal swamp origin (Best, 1984; Masson, 1986; Thibaudeau and Medioli, 1986; Bird, 1987) has been divided into three lithostratigraphic units by Boehner and Giles (1986). They are, in descending order, the Sydney Mines, Waddens Cove and South Bar Formations.

The Sydney Mines Formation is 385 m (Bird, 1987) to 500 m thick (Best, 1984; Masson, 1986) and comprises grey mudstone, shale, siltstone and sandstone with minor red mudstone, siltstone, diagenetic carbonate, limestone (locally algal laminated and petroliferous) and major economic coal seams (Boehner and Giles, 1986). The strata contain remains of trees, ferns (Bell, 1938, 1944; Zodrow and McCandlish, 1980; Zodrow, 1982), spores (Barss and Hacquebard, 1967), fish, ostracodes, polycheate worms, gastropods, bivalves (Masson and Rust, 1983, 1984; Best, 1984; Vasey, 1985; Masson, 1986), thecamoebians and marsh foraminifera (Thibaudeau and Medioli, 1986). On the basis of the floral and spore assemblages, a Westphalian B - Stephanian age was assigned by Bell (1927, 1938, 1944), Bell and Goranson (1938a, 1938b), Hayes and Bell (1923) and Barss and Hacquebard (1967) to the strata designated as the Sydney Mines Formation. The base of the formation is regionally and locally diachronous (Giles, 1983; Rust *et al.*, 1987).

The coal seams, of high volatile A bituminous rank (Hacquebard and Donaldson, 1970), are laterally continuous and can be traced across the basin (Haites, 1951; Boehner and Giles, 1986; Hacquebard, 1986). Hacquebard (1986) proposed that the Harbour seam, the best developed and most productive coal seam of the basin, may actually extend as far north as the St. Lawrence River Channel (a distance of 240 km) and to the west into the Gulf of St. Lawrence Coal Basin (Hacquebard, 1986) where it is known as the 7 Foot seam. Coal seams form 6% of the Sydney Mines section (Bird, 1987). They have been mined since 1720 and represent the largest coal reserve in Eastern Canada (Calder *et al.*, 1985). Currently, coal is being mined from the Hub seam at Point Aconi and the Harbour and Phalen seams near New Waterford.

Oil Shale

The first reference to oil shale in the Sydney Basin was given by Hartley (in Selwyn, 1871) who reported 3 ft. (1.0 m) of oil shale and black fire clay below the Sixfoot seam (?Phalen seam: Hacquebard and Donaldson, 1969) at New Campbellton (Fig. 15). The oil shale was reported to be "soft and with a slight heat gives a gas burning with a bright carbonaceous flame" (Selwyn, 1871, p. 5). The black shale and limestone, variously described by Vasey and Zodrow (1983), Masson and Rust (1983, 1984), Best (1984), Masson (1986), Bird (1987) and Gibling and Kalkreuth (in press) and tested by Kalkreuth and Gibling (1987c), comprise the oil shale lithologies. The limestone includes lithic arenaceous dolomite - lithic wacke biosparite, rich

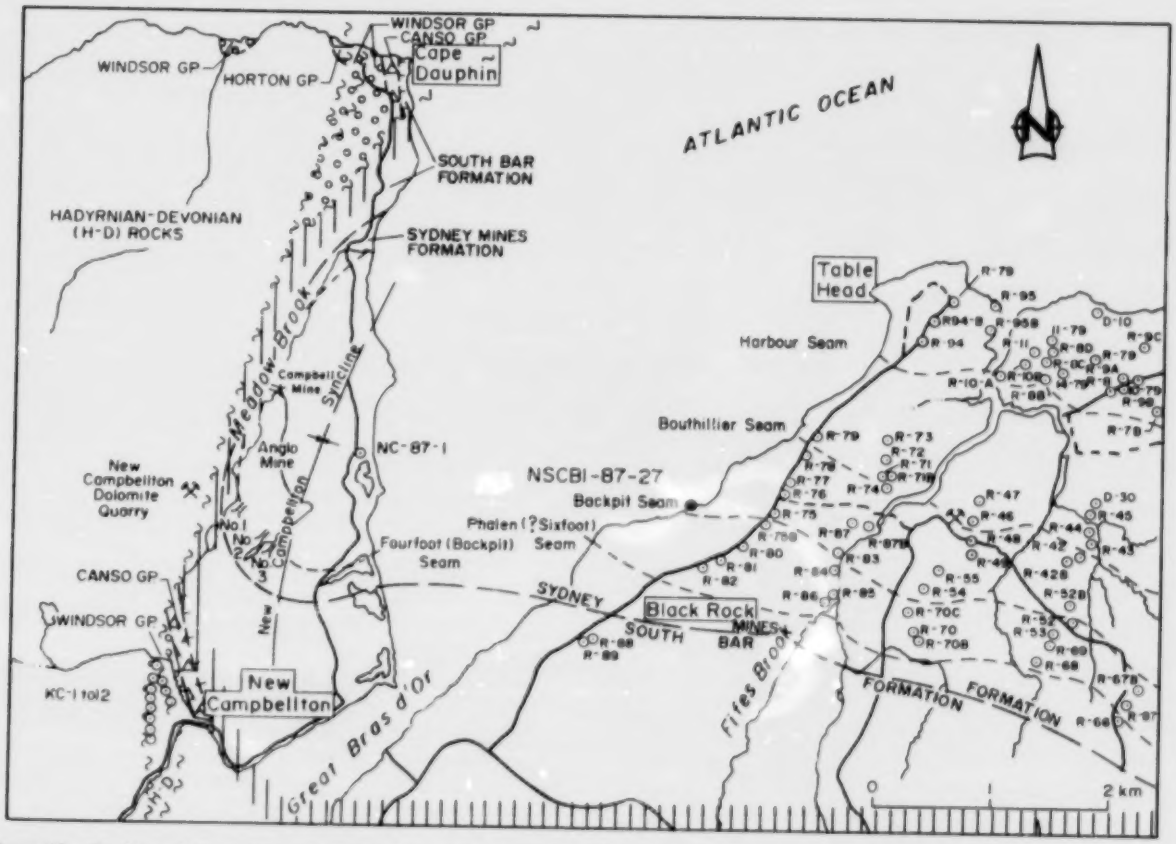

Figure 15. Geology of the western onshore portion of the Sydney Basin (after Boehner and Giles, 1986; MacNeil, 1988) showing the location of drillholes and outcrop samples taken for testing. See Appendix 1.11a, 1.11c and 1.11d for results of the analyses.

in silt- and fine sand-sized material, and black algal laminated biohermite commonly bivalve-bearing and possessing a brownish streak and petroliferous odour when freshly broken (Bird, 1987). The limestone is intimately associated with coal, is laterally continuous, and accounts for about 2% of the Sydney Mines Formation (Bird, 1987).

Samples of massive petroliferous limestone (lithic dolomite/biosparite of Bird, 1987) (0.11-0.40 m thick beds) associated with the Emery and Backpit seams and pelecypod- and fish-bearing black shale (?biohermite of Bird, 1987) (0.25-0.60 m thick beds) associated with the Hub, Phalen and Backpit seams were obtained from coastal exposures (Figs. 15, 16) for testing of hydrocarbon yield by Rock-Eval pyrolysis (the results are reported in Appendix 1.11a). Selected samples were also investigated by organic petrology, mineralogical analyses (X-ray diffraction) and combustion performance testing (reported in Appendices 1.11b-1.11d).

The Rock-Eval pyrolysis results show variable organic contents (1.2-26.3 wt.%) and hydrocarbon yields (1.8-51.5 l/t); the lowest yields were obtained from beds associated with the Phalen seam at Dominion Beach and the highest yields were obtained from beds associated with the Hub seam at Glace Bay. The organic matter is within the petroleum generation zone of thermal maturity (TMAX 435-441°C) and has hydrogen indices (HI=142-374) consistent with material of a humic (i.e. vitrinite, inertinite) to mixed (variable content including vitrinite, inertinite, exinite) maceral assemblage.

Mineralogical analyses of two samples, from the Phalen and Backpit seams, show that about half (48-67%) of the mineral component is carbonate (mostly calcite with minor siderite) with lesser amounts of clays (22-28%: illite, kaolinite) and quartz (6-16%). Combustion performance testing of these two samples shows high ash (68-76%) and low calorific (785-875 BTU/lb.) values.

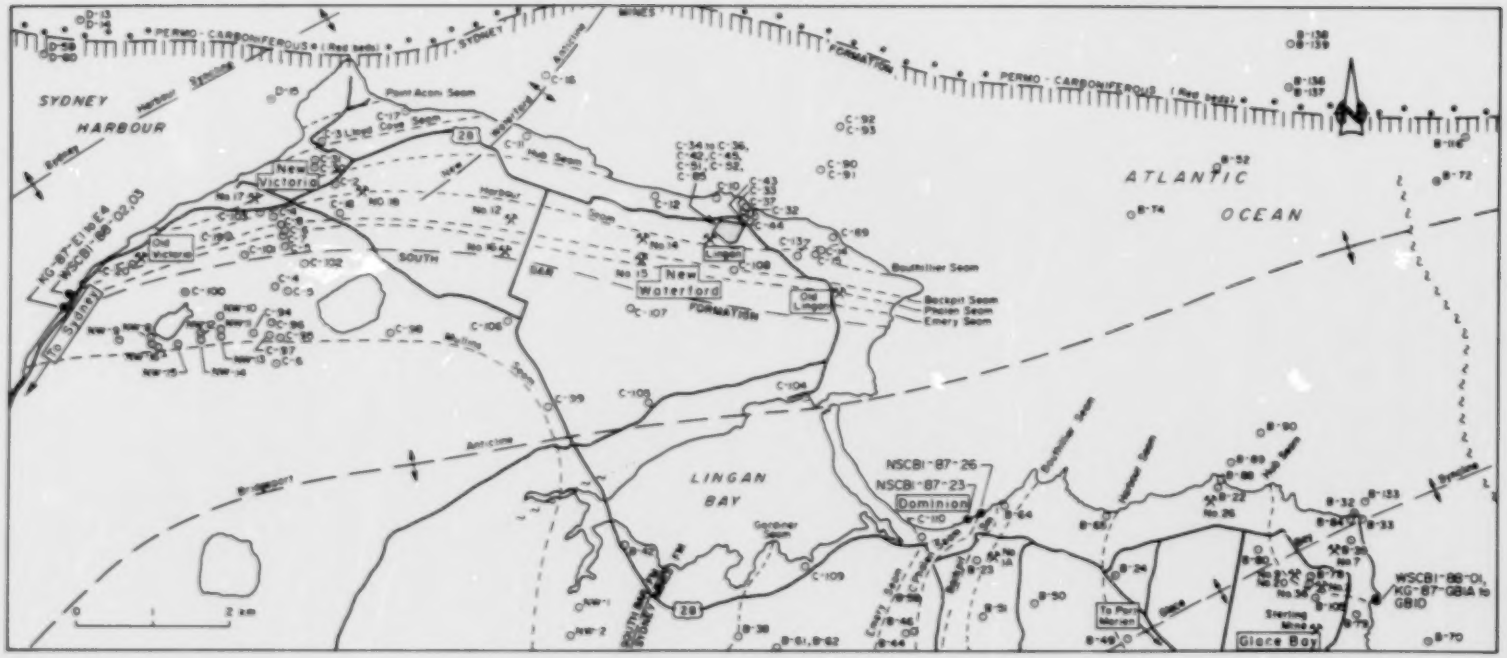

Figure 16. Geology of the central onshore portion of the Sydney Basin (after Boehner and Giles, 1986) showing the location of drillholes and outcrop samples taken for testing. See Appendix 1.11a-d for results of the analyses.

Analyses of black shale (?biohermite of Bird, 1987) associated with the Emergy seam (E.S.) at Victoria Mines and the Hub seam (H. S.) at Glace Bay by Kalkreuth and Gibling (1987c) showed higher organic carbon contents (0.05-15.3%: E. S.; 6.9-40.2%: H. S.) and hydrocarbon yields (up to 73.6 l/t: E. S; up to 194.1 l/t: H. S.; Appendix 1.11a) than obtained by our testing. Petrographic study of these same samples by Kalkreuth and Gibling (1987c) showed the organic matter to be predominantly of terrestrial origin and to comprise a mixture of sporinite, vitrinite and inertinite (Appendix 1.11b). With the exception of one sample, which is transitional to a coaly shale, the high yield samples owe their yield to an organic component rich in spore remains. Potter (1977) sampled in detail the Sydney Mines Formation section exposed at Port Morien. Contrary to the data presented here, his investigations and testing showed that the beds there had little or no hydrocarbon content.

The data presented here show that oil shale grade lithologies with yields of 48.6-73.6 and 51.5-194.1 l/t are known at Victoria Mines (above the Emery seam) and Glace Bay (above the Hub seam), respectively. Petrographic analyses show that the organic component contains abundant hydrogen-rich matter and mineralogical analyses indicate that carbonate minerals constitute a significant proportion of the inorganic component of these beds.

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Additional Selected References: Sydney Basin

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Trenton Syncline

Stratigraphy, Age and Depositional Environment

The first description of oil shale from the region north of Stellarton Basin, the Trenton Syncline (Fig. 17), was given by Poole (1863; Table 1). The oil shale is contained within the Merigomish Formation, Pictou Group, of Yeo (1985). The formation comprises a coal- and oil shale-bearing sequence of predominantly grey, medium- to coarse-grained lithic sandstone with minor conglomerate interbedded with reddish mudstone (Yeo and Ruixiang, 1986, 1987; D'Orsay *et al.*, 1986; Naylor *et al.*, 1987c). Drilling near the centre of the syncline by the Nova Scotia Department of Mines and Energy in 1986 (hole P58: Fig. 17) indicates a thickness of at least 550 m for the formation.

The formation has been divided into two members, Big Island and Smalls Brook (D'Orsay *et al.*, 1986). The Big Island Member consists of a series of multistoried grey channel sandstones (up to 100 m thick), of possible braided or anastomosing origin, with intervening beds of red and grey mudstone and siltstone of floodplain origin, and minor thin coal seams (D'Orsay *et al.*, 1986; Yeo and Ruixiang, 1987). The nature of the upper contact is unknown.

The Smalls Brook Member, the basal part of the Merigomish Formation, is characterized by a northerly thinning sequence of light grey calcareous sandstone and siltstone transitional to stromatolitic limestone ("Moose Fraser's limestone": Logan and Hartley, 1869; Haites, 1956; D'Orsay *et al.*, 1986) and coal (Munro seam: D'Orsay *et al.*, 1986). The Munro coal seam (Moose Fraser's limestone) is a distinctive marker that can be traced along strike for about 7 km (Haites, 1956; Fig. 17) and down dip, by diamond-drilling, for a distance of 7 km (D'Orsay *et al.*, 1986). The limestone was quarried "for burning" at a site some 3 miles (4.8 km) east of New Glasgow and the overlying coal was also mined for "the purpose of burning the limestone" (Logan and Hartley, 1869, p. 14). A sequence of grey shale, sandstone, thin coal and oil shale overlies the Munro seam - Moose Fraser's limestone section. The sequence of coal - limestone - oil shale and associated clastics probably owes its origin to a forest mire and shallow brackish lake setting (D'Orsay *et al.*, 1986; Yeo and Ruixiang, 1987). The upper contact with the Big Island Member is an erosional one, which probably explains the thinning of the Smalls Brook Member northerly away from the southern margin of the syncline. The basal contact of the member with the New Glasgow conglomerate (Cumberland Group) is disconformable.

The strata have been assigned to the Lower Pictou Group and palynological analyses of suites of coals indicate an age of late Westphalian C to Westphalian D (Naylor *et al.*, 1987c) to possibly Stephanian (Yeo and Ruixiang, 1987). The age determined from palynomorphs suggests that the strata of the Trenton Syncline are partly coeval with the Stellarton Formation.

Although the relationship between the Stellarton Formation and Merigomish Formation (observed in fault contact or separated by a narrow ridge of east-trending Cumberland and Canso Group rocks) is unknown, the two basins were probably not connected. The Stellarton Formation was probably confined to the Stellarton Basin whereas the Trenton Syncline lay initially to the northwest; juxtaposition of the time-correlative sequences was brought about by dextral strike-slip movement along the Cobequid Fault (Yeo and Ruixiang, 1987).

Oil Shale

The first reported occurrence of oil shale in the Trenton Syncline was given by Poole (1863). Poole noted the presence of bituminous shale and oil shale beds, 0.5-1.0 ft. (15-30 cm) thick, that cross Smelt Brook. He described the shale as friable and containing remains of *Poacites*, *Lepidodendron*, *(?)Paleoniscus* fish (jaws, teeth, scales, sabre-shaped spines) and coprolites. One oil shale bed, 30 cm thick, was reported to be relatively rich. Fletcher (1907) later reported that drilling south of Loudon Brook, 1.5 mi. (2.4 km) north of Trenton, intersected blackish-grey and black argillaceous shale full of ostracods and fish remains (spines, teeth, scales and coprolites) similar to those described by Poole in 1893. Swinnerton (1930) sampled the shale exposed on Smelt Brook for oil yield testing. The significance of these three reports have, apparently, been overlooked by later workers. West (1944b) reported that no oil shale was known in the area, and as a result considered it unfavourable for petroleum exploration.

In addition to occurrences noted by Poole (1863), Fletcher (1907) and Swinnerton (1930), oil shale beds have been identified in Smalls Brook and in two exploratory drillholes, P57 and P58 (Fig. 17). Hole P57 intersected 29 oil shale beds

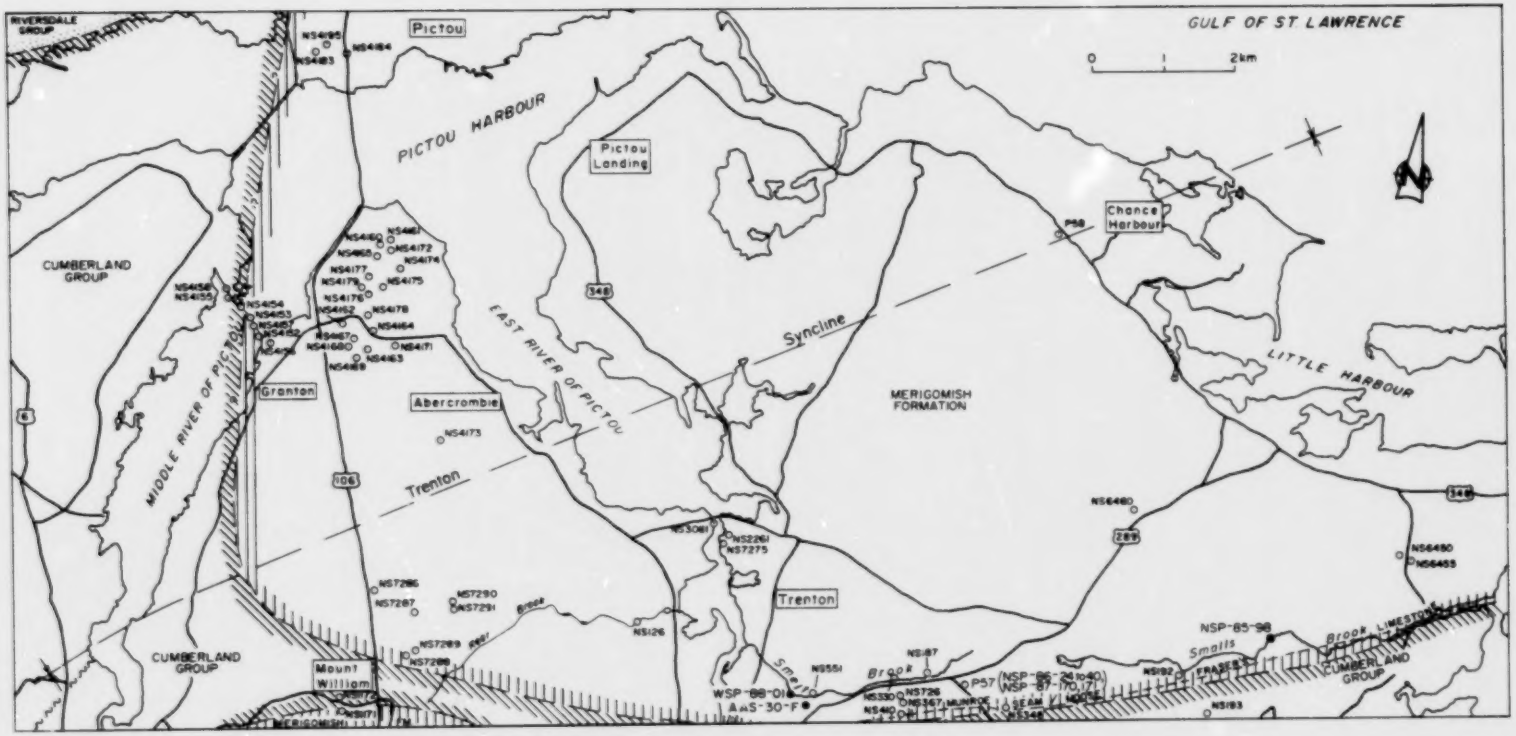

Figure 17. Geology of the Trenton Syncline area (after Haites, 1956; Gillis, 1985; D'Orsay et al., 1986; Yeo, 1987a; Naylor et al., 1989) showing the location of drillholes, and drill core and outcrop samples taken for testing. See Appendix 1.12a-d for results of the analyses.

ranging in thickness from 0.2-1.0 m (avg. 0.4 m thick). Twenty-eight beds were encountered at a depth of 13-61 m, accounting for 21% of the section thickness, and one oil shale bed was encountered at a depth of 95.40-95.90 m. In hole P58 only one bed was intersected; it was cored at a depth of 447.53-447.64 m.

Samples of oil shale from Smelt Brook, Smalls Brook and drillhole P57 were analyzed by Rock-Eval pyrolysis and selected samples were studied for organic content, mineralogy and combustion performance (Appendices 1.12a-d). The oil shale is clay-rich (clays constitute 80% of the mineral component) and dark grey to black in colour. Samples contain vitrainous coaly laminae, plant remains, pelecypods, ostracodes and, locally, fecal pellets. Some of the oil shale beds are rich in boghead shale and contain sections that fluoresce, in a manner similar to the boghead shale of the Stellarton Basin, when exposed to long wavelength ultraviolet light.

Rock-Eval pyrolysis results indicate that the oil shale is thermally mature (slightly), contains 4-16% organic carbon and gives hydrocarbon yields of 8.5-55.0 l/t. Combustion testing of an oil shale bed rich in boghead shale gave high ash (82.15%) and low calorific (1302 BTU/lb.) values. Hydrogen indices obtained from the Rock-Eval data are consistent with organic matter derived from a predominantly algal source (i.e. the boghead shale portions of some oil shale beds) or a mixed assemblage of organic matter types. Organic petrology of a sample with a hydrogen index typical of the mixed assemblage verified this interpretation of the data; it showed organic matter comprising a groundmass of weakly fluorescing matter (33%), sporinite (29%), cutinite, vitrinite and inertinites (36%), and minor telalginite (2%).

Oil yield testing of the Trenton Syncline shale by Swinnerton (1930) gave comparatively low values. The sample tested by Swinnerton from Smelt Brook gave a yield of only 0.2 l/t.

Our data confirm the presence of oil shale grade lithologies in the Trenton Syncline. These oil shale rocks are rich in algal (telalginite) organic matter and are therefore considered to be boghead shale; along with Stellarton, these are the only two areas of the Province where this type of oil shale is known. The oil shale rocks are confined to the 100 m thick coal-bearing section above the Munro seam (Moose Fraser's limestone). This section is laterally continuous along strike for at least 8.5 km (Fig. 17) but pinches out over a downdip (toward the centre of the syncline) distance of 4 km and appears to be confined to the southern basin margin areas. Marginal areas adjacent and lateral to sites of known oil shale occurrences, such as Rear Brook (Fig. 17) and Big Island (15 km north of Trenton), warrant investigation of potential oil shale thickening and quality improvements.

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ECONOMIC POTENTIAL

Previous attempts at oil shale developments in Nova Scotia have historically been short-lived, uneconomic ventures that focused exclusively on hydrocarbon production: in Stellarton from 1852-1859 and 1929-1930 (Douglas and Campbell, 1942), in Antigonish (Big Marsh) around 1865 (Ells, 1909), and at McAdams Lake about 1890 (Neville, 1891). Further evaluations of oil shale potential have also led workers to conclude that shale oil yields are generally too low for commercial exploitation (Douglas and Campbell, 1942; Kendler, 1950; Macauley *et al.*, 1985; Naylor and Smith, 1986b, 1988a; Naylor, *et al.* 1987a). These workers have recognized that the economics of oil shale development must be enhanced through less expensive mining and retorting costs, higher oil yields and prices, additional use for the by-products of oil shale distillation, or use of the rocks and their products as a replacement or extender for imported commodities.

RECOMMENDED DIRECTIONS FOR OIL SHALE DEVELOPMENT

It is concluded that future investigations evaluating the potential of Nova Scotia oil shale should focus primarily on improvements in retorting technology and on a process for indirect use applications. In particular, these investigations should be directed toward the Stellarton oil shale since it represents the most attractive deposit in terms of yield (Fig. 18), quantity and potential for inexpensive surface (open-pit) mining. In New Brunswick, for example, the oil shale deposits are uneconomic on the basis of their oil yield alone (Macauley and Ball, 1982; Smith, 1985) but they are currently attracting attention because of their carbonate-rich character. The by-product potential that they offer is in shale oil recovery followed by co-combustion with high sulphur coal (from Minto, N. B.) during thermal power generation to reduce

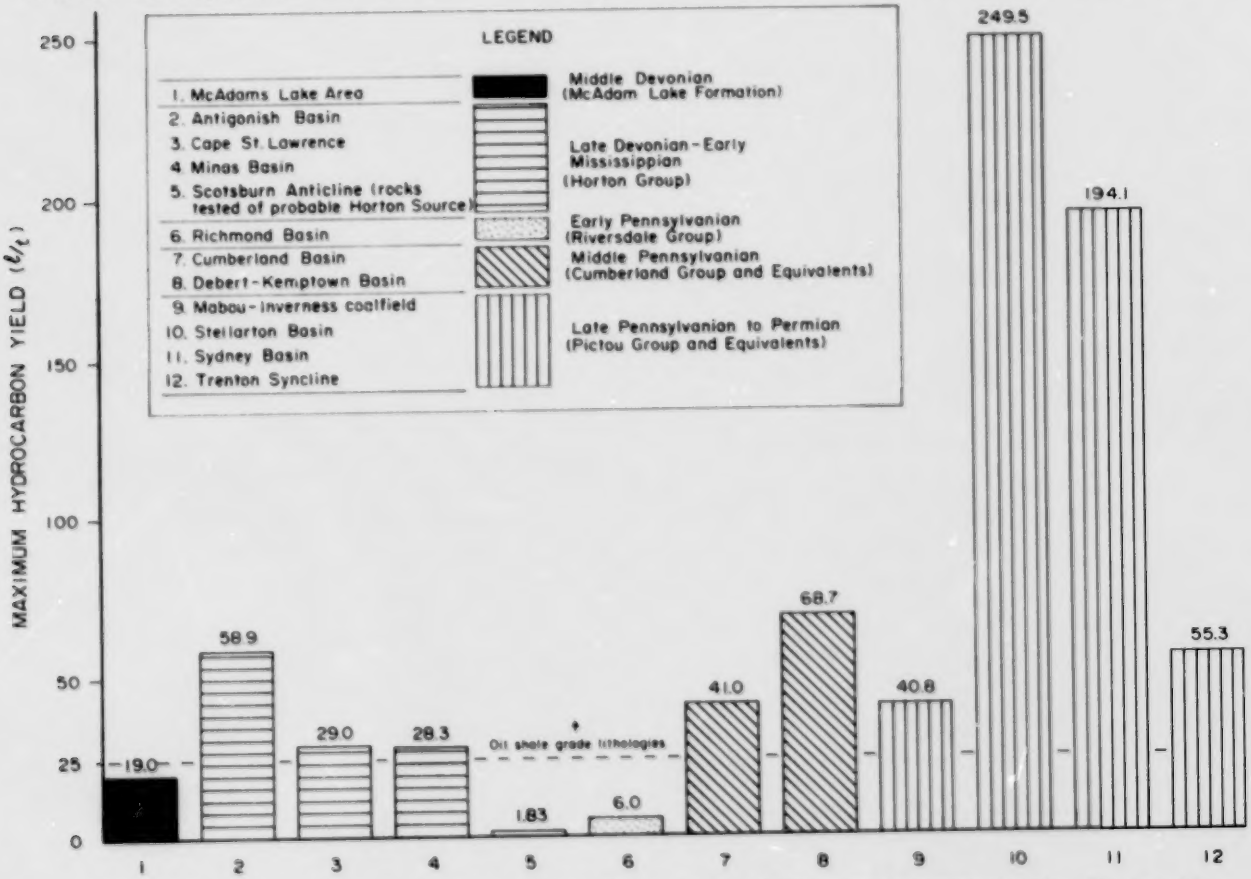

Figure 18. Maximum hydrocarbon yields obtained from rocks in 12 areas of Nova Scotia reported to contain oil shale. The dashed line indicates the lower limit of oil yield, 25 l/t, at which rocks are considered to be of oil shale grade.

sulphur emissions (Macauley *et al.*, 1985). Although the co-combustion process is not suited to the silicate-rich Stellarton oil shale, it serves to illustrate the type of innovative approach required to develop an otherwise uneconomic resource.

Retorting Technology

Effort has been directed toward improvements in retorting technology, principally with Stellarton oil shale, at the Technical University of Nova Scotia, Halifax. Flynn (1926) investigated the effects of heating oil shale under different conditions (variable retorting rates, progressive heating, variable size fractions or lumps, retorting with steam, and retoring under pressure and vacuum). His work demonstrated that the heating rate during pyrolysis has a considerable effect on the pyrolysis products: fast rates yield the greatest quantity of liquid product but lower quality oil; slow rates give lower yields but higher quality oil with lower specific gravity. Rockwell (1985) has studied the treatment of oil shale by heavy liquid separation and (Wilfley) tabling, conventional flotation and oil agglomeration/brine flotation for the purpose of concentrating the organic component and thereby increasing hydrocarbon yields. Rockwell's (1985) experiments indicated that crushing/grinding followed by heavy liquid separation provided the most favourable results. In particular, oil shale samples crushed to size fractions of 0.250 - 0.600 mm and 0.150 - 0.250 mm followed by heavy liquid separation generated higher Fischer Assay values than initial values obtained from raw crushed oil shale (i.e. crushed to 2.36 mm, the standard crushed size for the ASTM D3904-80 Fischer Assay method; ASTM, 1984). The other methods of treatment showed only limited success in producing higher yields.

Also related to improvements in oil shale retorting technology are the studies of flash hydropyrolysis of coal being carried out at the Ontario Research Foundation. In this process, coal is rapidly pyrolyzed in the presence of hydrogen at high temperatures and pressures of up to 10.34 MPa (Starzomski, 1987). Flash hydropyrolysis application to oil shale or oil shale/coal mixtures offers potential for better quality and yields of liquid products (Starzomski, 1987).

Indirect Use Applications

Potential indirect or substitute-extender uses of oil shale, with a value-added component to enhance the economics of utilization, have been investigated. These replacement-extender applications include: utilization of waste products as industrial materials commodities, ammonia recovery, co-processing to enhance or extend resource utilization, and replacement for imported products.

Waste and By-product Residue

One indirect application of oil shale follows combustion to generate electricity and involves use of the co-processed oil shale and coal ash to produce industrial materials. Some effort has been directed toward investigating the use of Stellarton oil shale as raw material for concrete by Kendler (1950) and Haw (1958) and as additives for paint and rubber products by Kendler (1950). In Stellarton, a candidate for this scheme is oil shale bed 58 which overlies the Acadia seam. Recent drilling by Pioneer Coal Ltd. has identified a coal resource area accessible through open-pit mining (Smith *et al.*, 1989b).

Use of oil shale ash in brick and cement production was successfully carried out in the German oil shale industry (Macauley and Ball, 1982) and oil shale ash is currently used by cement producers in the USA, USSR and China (Knutson *et al.*, 1989).

Ammonia Recovery

Another indirect use of oil shale involves recovery of ammonia gas during the pyrolysis process to produce ammonium sulphate, an ingredient of fertilizer. Ammonium sulphate yields of 4.3-20.5 kg/t have been reported for various Stellarton oil shale beds (Ells, 1909; Flynn, 1926) and up to 19.0 kg/t for oil shale sampled from the Big Marsh deposit at Antigonish (Ells, 1909). In the Scottish oil shale industry ammonium sulphate, as well as paraffin wax, were produced as by-products of shale oil extraction; ammonium sulphate production was considered to be one of the principal sources of profit from the distillation process (Ells, 1910).

Co-processing and Enhancing

Macauley *et al.* (1985) suggested that the co-

processing of the Stellarton Oil Coal seam and underlying boghead shale-rich oil shale (bed 45) offers potential for exploitation. The potential offered by this scheme is the recovery of oil and gas through distillation of the oil shale-coal mix, followed by electric power generation through burning of the residue. Coal would offer some contribution to the overall liquid yield (see Table 6 for a summary of hydrocarbon yield testing results for selected Stellarton coals). Stellarton oil shale bed 45 was mined from 1852-1859 for use in gas making, as a mix for coal, as an enricher in the manufacture of illuminating gas and for distillation. The project was abandoned when cheaper conventional crude oil was discovered in Pennsylvania in 1860 (Douglas and Campbell, 1942).

This study indicates that the high hydrocarbon yields and calorific values obtained from the cannel shale of Stellarton oil shale bed 22 also offers the potential for shale oil recovery followed by combustion of the residue for electrical generation. This potential is particularly attractive since the cannel shale-bearing oil shale bed overlies a bed of claystone currently mined, by open pit methods, for use in brick manufacture; the oil shale is stripped away from the underlying claystone and set aside as waste. The cannel shale was mined for its shale oil yield in 1930 by Torbanite Products Limited. The project was abandoned when the company's plant burned down late in 1930 (Messervey, 1930; Douglas and Campbell, 1942).

Numerous other oil shale beds within the Stellarton Basin and oil shale occurrences elsewhere in the Province, all associated with coal, could offer a similar potential. Such occurrences include petroliferous limestone of Cumberland Basin and Sydney Basin, cannel shale of the Mabou-Inverness coalfield and boghead shale of the Trenton Syncline.

Replacement and Substitution

Shale oil may be used as a replacement for the conventional petroleum additive in asphalt. This potential use of oil shale is currently being investigated using oil shale from the western USA (Colorado) by the New Paraho Corporation. Recent reports indicate that use of shale oil improves pavement resistance to moisture damage and binder embrittlement (Lukens, 1989) which is particularly important in freeze-thaw climates such as here in Nova Scotia.

Table 6. *Summary of laboratory test results for selected coal seams from the Stellarton Basin (see Appendix 1.10b for details of the results). TOC = Total Organic Carbon Content.*

		ANALYSIS		
COAL SEAM		OIL YIELD (l/t)	TOC (WT%)	HYDROGEN INDEX (H.I.)
Sixfoot	Range	107.7-142.0	50.6-65.3	209-300
	n	2	2	2
Widow Chis. B	Range	75.7	65.6	153
	n	1	1	1
McLeod	Range	2.9-158.5	1.6-60.2	123-386
	n	28	28	28
Foord	Range	42.7	27.6	153
	n	1	1	1
Cage	Range	36.2-124.3	27.1-74.8	173-213
	n	3	2	2
Oil Coal	Range	6.2-101.2	7.3-54.6	104-207
	n	5	5	5

STELLARTON OIL SHALE POTENTIAL

Multiple Use Applications

The oil shale at Stellarton is ideally located when considering the potential multiple uses discussed above. Figures 19 and 20 show that the Stellarton oil shale is situated within 10 km of coal-fired electric generating plants, concrete ready-mix plants and an asphalt plant.

Implications for Coal Resource Exploration

An immediate use for oil shale from the Stellarton Basin lies in the ability to recognize distinct oil shale beds within sections of the Stellarton Formation that are separated by 1-2 km. The oil shale beds make excellent stratigraphic markers and hence are useful for section correlation. As well, the association of some oil shale beds with coal seams within the Stellarton Formation has been used as a guide to coal exploration (Naylor *et al.*, 1986). In particular, lake (oil shale) to swamp (coal) paleo-environmental trends within the Stellarton Basin have applications in exploring for undiscovered coal (Naylor and Smith, 1988b).

Implications for Petroleum Exploration

Finally, the occurrence of oil shale and organic-rich shale in Nova Scotia may have significant implications for hydrocarbon exploration. Especially important are those occurrences contained in Horton (Antigonish Basin, Cape St. Lawrence area and Minas Basin), Cumberland (Cumberland Basin) and Pictou (Mabou-Inverness coalfield, Stellarton Basin,

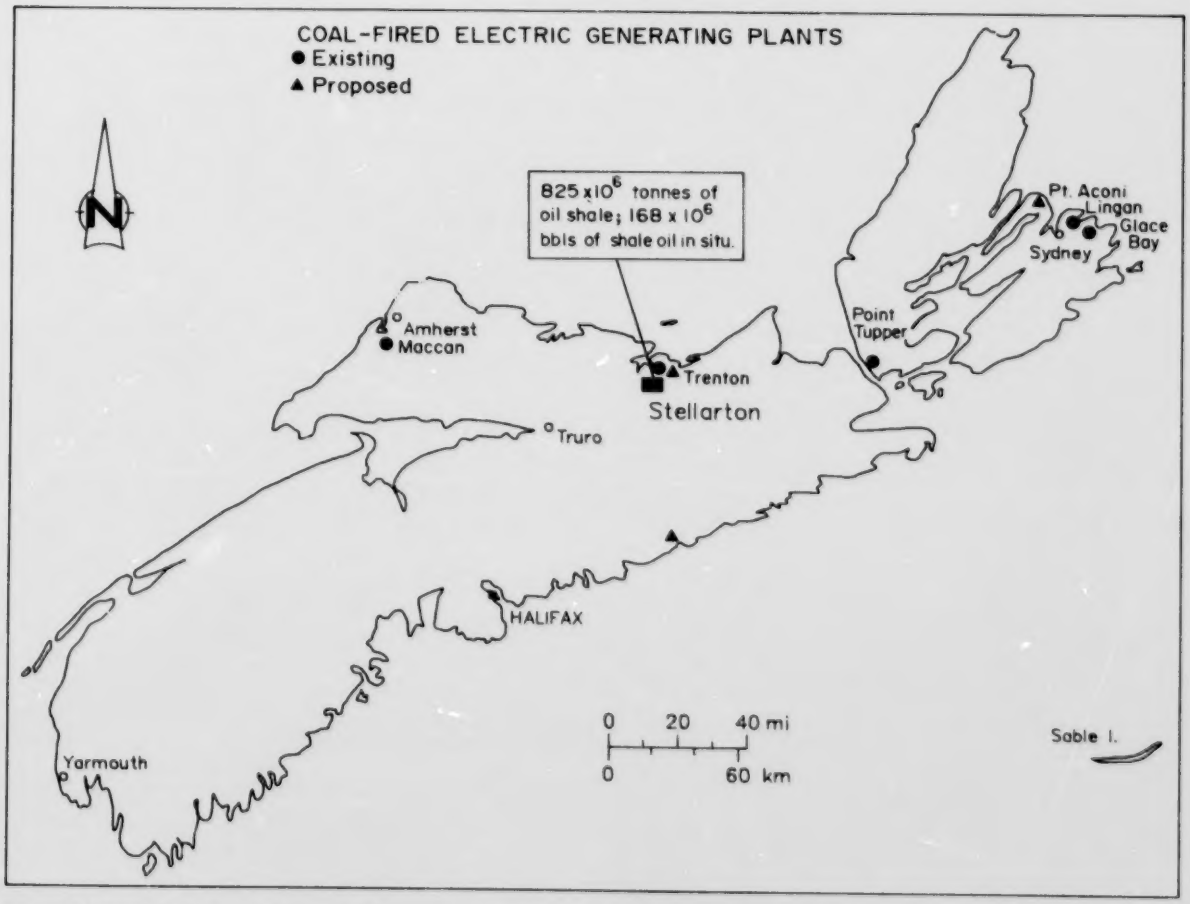

Figure 19. Location of the Stellarton oil shale resources relative to existing and proposed coal-fired electric generating plants.

Sydney Basin and Trenton Syncline) Group strata. The presence of hydrocarbon shows and accumulations within such strata or age equivalents elsewhere the Maritimes (Moncton Basin, Minas Basin, Antigonish Basin, Lake Ainslie area, Cumberland Basin and Stellarton Basin) suggests that the strata may have acted as regional petroleum source rocks (Naylor *et al.*, 1987a; Naylor and Smith, 1988a). The regional source rock potential of the areas studied in this project is currently part of an investigation by McMahon (in prep.).

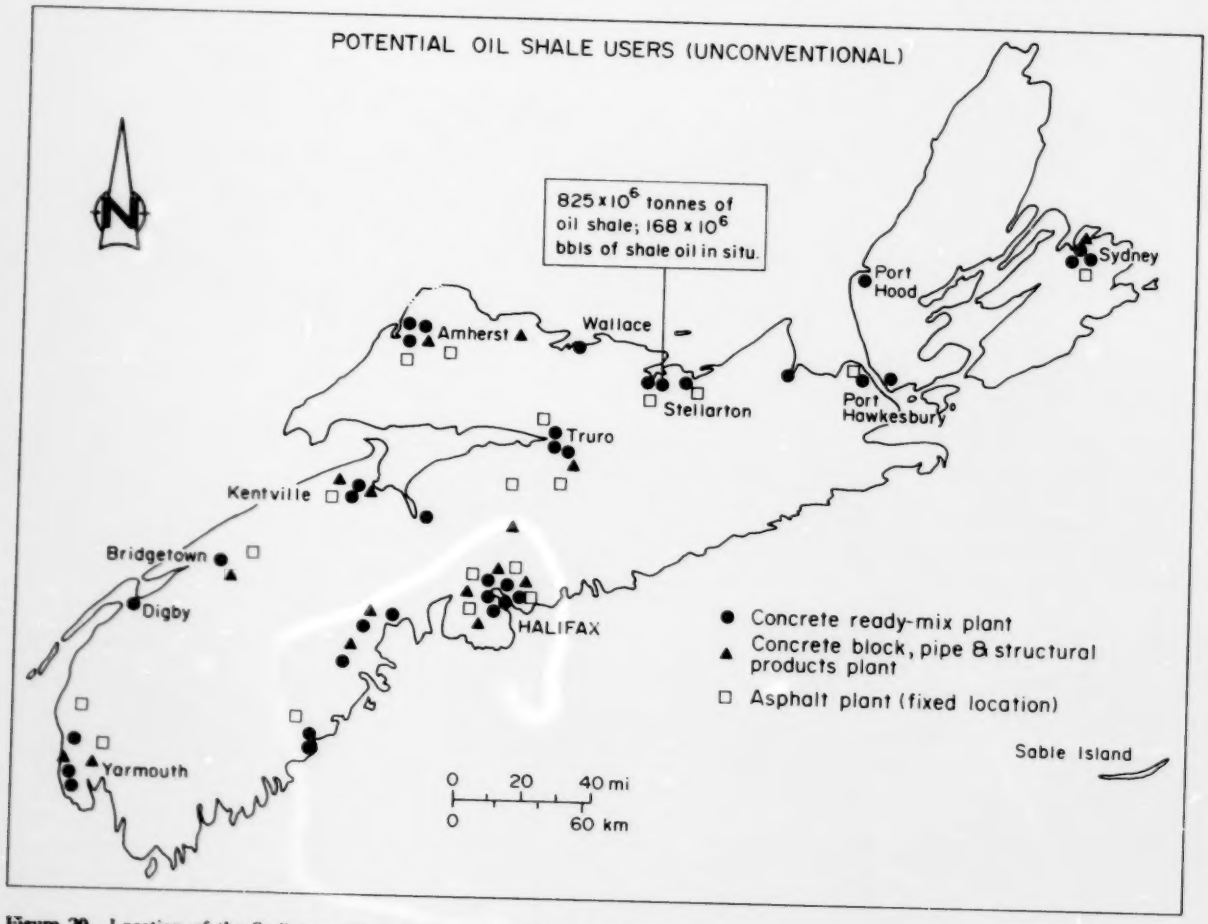

Figure 20. Location of the Stellarton oil shale resources relative to existing concrete ready-mix plants, concrete block, pipe and structural products plants, and asphalt plants.

SUMMARY

OIL SHALE RESOURCES

Oil shale, a term applied to rocks that yield 25 litres or more of hydrocarbons per tonne of rock upon retorting, is known to occur in nine areas in Nova Scotia (Figs. 1, 18). All these rocks are of Upper Paleozoic age (Fig. 2) and occur within the late Devonian-Tournaisian and Westphalian B-D strata of the northern mainland and Cape Breton Island and within the Westphalian A-B strata of northwestern Nova Scotia. Oil shale development has been attempted at two of these areas, Stellarton and Antigonish (Big Marsh), but they were only short-lived events. Oil shale was mined at Stellarton from 1852-1859 and 1929-1930 and at Antigonish circa 1865.

Stellarton Basin

The largest oil shale resource known in Nova Scotia is from the 2600 m thick Westphalian B-D coal-bearing Stellarton Formation. The formation is situated within the 6 km x 18 km Stellarton Basin and contains 60 silicate-rich oil shale beds, all of lacustrine origin. The oil shale beds vary in thickness (average of 5 m and maximum of 35 m) and are interbedded with sandstone, siltstone, claystone, coal and/or minor conglomerate. Most (90%) of the oil shale beds are fissile shale (avg. yields of 25 l/t or less) with thin sections of cannel shale (avg. yields of 40 l/t). The remaining beds are rich in boghead shale (avg. yields of 110 l/t). A total *in situ* resource of 825 x 10^6 tonnes of oil shale giving 168 x 10^6 bbls of shale oil is estimated from oil shale beds 1-45 (Table 5). Resource estimates for oil shale beds 46-60 are currently unobtainable due to lack of oil yield information.

Antigonish Basin

The second largest resource occurs within the 500-1230 m thick South Lake Creek Formation, late Devonian-Tournaisian Horton Group, in the Antigonish Basin. Oil shale occurs at two localities, Big Marsh and Beaver Settlement, that are 10 km apart. The oil shale bed averages 117.5 m thick along strike for 4.8 km at Big Marsh and 61.6 m along strike for 1.6 km at Beaver Settlement. The oil shale is dominated by low yielding fissile oil shale (avg. yield of 14.6 l/t) with thin sections of higher yielding massive (cannel) oil shale (with maximum yields of 58.9 l/t). A total *in situ* resource of 738 x 10^6 tonnes of oil shale giving 75.6 x 10^6 bbls of shale oil is estimated from the two areas (Table 4).

Other Localities

Westphalian B-D (Pictou Group) oil shale also occurs within the Mabou-Inverness coalfield (cannel shale), Sydney Basin (calcareous shale and petroliferous limestone) and Trenton Syncline (boghead shale); all are associated with coal. Late Devonian-Tournaisian (Horton Group) oil shale also occurs in the areas of Cape St. Lawrence (silicate-rich shale) and Minas Basin (carbonaceous and coaly shale). Oil shale of late Westphalian A - Westphalian B age is known in the Cumberland Basin (Cumberland Group: laterally extensive calcareous shale and petroliferous limestone) and in the Debert-Kemptown Basin (Delaney formation: cannel shale); both occurrences are associated with coal. The oil shale beds at these areas are generally less than 1.5 m thick, only a few attain a thickness of up to 3.0 m, with the higher yielding portions of the beds confined to sections only 30 cm thick. Thus, they represent only limited resources.

OIL SHALE DEPOSITION

Oil shale deposition during late Devonian-Tournaisian time occurred within fault-bounded extensional basins that formed following the Acadian Orogeny in northern and western Cape Breton Island and on mainland Nova Scotia (Murray, 1960; Hamblin, 1988; Martel and Gibling, 1989) (Figs. 1, 2). The basins probably included components of deep, annually stratified lakes in Cape Breton (Murray, 1960), small, shallow algal lakes bordered by swamps at Antigonish (Murray, 1960), and a hydrologically open lacustrine system with a gently sloping shoreline transitional to a swamp environment within the Minas Basin (Martel and Gibling, 1989).

During Westphalian A-B time, the Cumberland and Debert-Kemptown Basins were the main depocenters of continental deposition. Deposition of petroliferous, pelecypod-bearing limestone and shale associated with the coal-bearing Cumberland Group in the Cumberland Basin is attributed to brackish, standing water conditions (Duff and Walton, 1973). The lateral continuity of the

pelecypod-bearing limestone suggests that brackish conditions were regionally extensive. Deposition of cannel shale within the Debert-Kemptown Basin probably represents ephemeral lacustrine conditions that drowned the coal-forming swamps and resulted in their termination.

During Westphalian B-D time regionally extensive coal formation and fluvial sedimentation occurred within the Sydney Basin and Gulf of St. Lawrence region of the Maritimes Basin. Oil shale beds in these areas are associated with coal seams, where they occur within the roof and/or floor strata. The oil shale probably represents widespread flood events that drowned the swamps and, in some cases, terminated peat accumulation. Within the Stellarton Basin, however, restricted sediment supply to a relatively small and rapidly subsiding basin allowed lacustrine conditions, in which algae flourished, to develop. Lacustrine conditions, similar to those of Stellarton, probably also existed from time to time northward within the Trenton Syncline. Oil shale beds contained within Pictou Group strata of the Trenton Syncline, although thinner and less abundant, are lithologically and chemically similar to those of Stellarton.

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